JOURNAL OF THE A·I·E·E·

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
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American Institute of Electrical Engineers

COMING MEETINGS

Pacific Coast Convention, Seattle, Washington, September 15-19

MEETINGS OF OTHER SOCIETIES

American Institute of Mining and Metallurgical Engineers, Salt Lake City, Utah, Aug. 31-Sept. 3.

N. E. L. A.—New England Division, Hotel Griswold, New London, Connecticut, Sept. 8-11; Rocky Mountain Division, Hotel Colorado, Glenwood Springs, Col., Sept. 14-17; Southeastern Geographic Division, Birmingham, Ala., Sept. 15-18; Great Lakes Geographic Division, French Lick Springs, Ind., Sept. 23-26.

Association of Iron & Steel Electrical Engineers, Benjamin Franklin Hotel, Philadelphia, Pa., Sept. 14-19.

American Electrochemical Society, Chattanooga, Sept. 24-26.

American Electric Railway Association, Atlantic City, Oct. 5-9.

Association of Railway Electrical Engineers, Hotel Sherman, Chicago, Oct. 20-24.

JOURNAL

OF THE

American Institute of Electrical Engineers

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
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Current Electrical Articles Published by Other Societies

Federation of Architectural and Engineering Society, Minn.

A Few Sidelights on Telephone Development, by F. E. Lister (Bulletin June 1925, Vol. 10, pp. 18-20)

Institute of Radio Engineers, Proceedings, June 1925

Power Amplifiers in Transatlantic Radio Telephony, by A. A. Oswald and J. C. Schelleng

Re-Radiation from Tunes Antenna Systems, by H. C. Forbes

Long Distance Radio Receiving Measurements in 1924, by L. W. Austin

Iron and Steel Engineer, June 1925

The Static Condenser on Steel Mill Loads, by R. W. Dudley

Western Society of Engineers, Journal

Transmission of Pictures by Telephone, by H. E. Ives, (May 1925)

Protective Relays for Central Station Systems, by O. J. Bliss, (May 1925)

Automatic Substations in Steel Mills, by G. P. Wilson, (June 1925)

Some Tendencies in Modern Power Plant Design, by W. M. Kenan, (June 1925)

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Technical and Social Interests Blend

You will never know a man until you have seen him in his own home, and a man's home is in the hearts of his family. A member of the Institute who brings his wife and children to the Annual Convention brings his home also and bids us enter. We gladly do so, and from that moment, we feel that there is a family relationship which binds all to one another as well as to the Institute. Membership in the Institute then assumes a different meaning; to the community of scientific and professional interests there is added a community of human interests, and this transforms the Institute into a spiritual being.

No organization can grow and prosper until it cultivates the spiritual elements of its life. That is the object of the social side of our conventions. Reading papers and discussing them supplies food for the intellect, but dancing, playing golf, or any other game with the members of your friends family, excursions and informal conversations, are feasts for the spirit, and without the guidance of the spirit, one cannot find the way into a man's heart. A scientific organization if it is to perform its highest mission, must be a union of hearts as well as a union of minds.

These were the thoughts which suggested themselves to my mind as I watched the various events at the Saratoga convention, and they confirmed my belief that the social part of the program of our conventions is just as important as the technical. The Institute is an autonomous living organism, and its life depends upon one almost as much as upon the other. The charming excursion and entertainment at Schenectady illustrates this point. There we saw a wonderful plant, the result of intellectual activity of the members of the Institute; that is, many of us thought so, and felt that we were justified in thinking so. Were not two of the most distinguished men of the General Electric Company Presidents of the Institute, and are not this company's able engineers and scientific men among the most enthusiastic members of the Institute? Of course, we were justified in our proud belief, but, nevertheless, the affectionate hospitality of that great organization was a welcome demonstration of the correctness of our judgment. It told us that the whole General Electric Company considers itself a part of our Institute family, and that our relationship is held secure not only by bonds of intellect but also of spiritual interests. As long as such bonds unite us to one another and to the great electrical industries of the United States, no one need feel anxious regarding the bright future of the Institute.

M. I. Pupin

Some Leaders of the A. I. E. E.

John William Lieb, the Seventeenth President of the A. I. E. E., was born in Newark, New Jersey, February 12, 1860. Attended the Newark Academy and Stevens High School, Hoboken, New Jersey; on graduation from the latter entered the Stevens Institute of Technology, Hoboken, New Jersey, in the class of 1880, graduating with the degree of Mechanical Engineer and receiving in 1921 the honorary degree of Doctor of Engineering from his alma mater.

In 1880, he entered the employ of the Brush Electric Company, Cleveland, Ohio, as Draftsman. Returning to New York in January 1881, he entered the employ of the Edison Electric Light Company as Draftsman in the Engineering Department. In 1881 he was transferred to the Experimental and Testing Department at the Edison Machine Works, Goerck Street, New York, engaged in researches and investigations under the personal direction of Mr. Edison. In 1882 he was assigned to the Pearl Street Station in general charge of the planning and installation of the electrical equipment, and on September 4, 1882, when the station was put into commission under the auspices of the Edison Electric Illuminating Company of New York, he was appointed its first Electrician.

In November 1882 he was selected by Mr. Edison to proceed to Milan, Italy, to direct the installation of the Milan Edison Station. On the organization of the Societá Generale Italiana di Elettricitá, Sistema Edison, he was appointed its Chief Electrician, then its chief engineer and finally Technical Manager and Director of Stations. The Milan Station was for a considerable time the largest and most successful electric light and power station in Europe. For his pioneer work in connection with the introduction of electric light and power service throughout Italy and the installation of the electric trolley system in Milan, he was decorated by the Italian Government a Knight Commander of the Royal Order of the Crown of Italy and later promoted to be a Grand Officer.

In 1894, Mr. Lieb returned to America as Assistant to the Executive of the Edison Electric Illuminating Company of New York, and later became third Vice President and General Manager, serving in this capacity until the company's absorption by the New York

Edison Company in 1901. His service in the reorganized company was first as Associate General Manager, then as Vice President, and finally as Vice President and General Manager, which position he at present occupies.

Mr. Lieb is a Vice President and a Director of The New York Edison Company, Vice President and member of the Board of Directors of the Yonkers Electric Light and Power Company, member of Board of Directors of The United Electric Light and Power Company and of The New York and Queens Electric Light and Power Company, Vice President of the Edison Electric Light and Power Installation Company, member of the Board of the International Power Securities Corporation, of the Brush Electric Illuminating Company, of the Empire City Subway Company, and President and Chairman of the Board of The Electrical Testing Laboratories.

Mr. Lieb is a Past President of the Edison Pioneers; a Past President and Fellow of the American Institute of Electrical Engineers, Past President of the Association of Edison Illuminating Companies, the National Electric Light Association and the New York Electrical Society; Past Vice President of the American Society of Mechanical Engineers and Fellow New York Academy of Sciences; Member American Society of Civil Engineers, Illuminating Engineering Society, American Association for the Advancement of Science, American Society for the Promotion of Engineering Education, Franklin Institute of Philadelphia and numerous other professional and civic organizations national and local. He is an Honorary Member of the American Society of Italian Engineers and Architects, and of the Society of Italian Railway Engineers and a member of the Associazione Electrotecnica Italiana, British Institution of Electrical Engineers, and the Newcomen Society of London.

On February 4, 1924, Mr. Lieb was awarded the Edison Medal by the American Institute of Electrical Engineers for his work in connection with the development and operation of electric central stations for illumination and power.

Revised Constitution and By-Laws

As announced in previous issues of the JOURNAL, the proposed amendments to the Constitution of the Institute, as submitted to the membership for a letter-ballot under date of February 25, 1925, were all adopted at the Annual Meeting of the Institute held May 15. Amended By-laws, as revised to harmonize with the amended Constitution, were adopted by the Board of Directors on June 25.

The principal changes made in the Constitution were as follows:

(a) The qualifications for admission to the grade of Associate were more clearly defined.

(b) The admission fee for the grade of Associate was increased from $5.00 to $10.00 and the annual dues for Assocates of six years or more standing were increased from $10.00 to $15.00.

(c) Life membership was placed upon an actuarial basis so that the fee to be paid depends upon the age of the applicant.

(d) Exemption from and remission of dues was provided to apply to members of long standing who have helped to build up the Institute and who for various reasons may find it a hardship to continue to pay annual dues.

(e) The procedure for the election of officers of the Institute was completely revised, as recommended by a special committee appointed by the Board of Directors to consider the various demands that have frequently been expressed by numerous members for improvement in the election procedure. Under the new plan a National Nominating Committee will be organized in the Fall of each year, consisting of fifteen members, one selected by the Executive Committee of each of the ten Geographical Districts and the remaining five to be selected by and from the members of the Board of Directors. Provision is also made for other nominees in addition to those officially named by the National Nominating Committee.

(f) The titles of the Treasurer and Secretary were changed to National Treasurer and National Secretary, respectively.

The principal changes made in the By-laws were for the purpose of definitely establishing the details of procedure in order to carry out the intent of the amended portions of the Constitution. The duties of the various committees of the Institute have also been more fully and definitely defined. Several new By-laws have been incorporated, including those relating to the organization and conduct of general conventions and regional meetings. Provision for the appointment of a counselor of each Student Branch was also made, these counselors to become ex-officio members of the Committee on Student Branches. Other amendments of minor importance were also included.

In formulating the amended Constitution and By-laws the Revision Committee carefully considered all the suggestions received from various Sections, Committees, and individual members of the Institute; and the two documents constitute a fairly complete code of procedure covering the established practise in carrying on the numerous activities of the Institute.

The amended Constitution and By-laws will be incorporated in the 1926 YEAR BOOK but in the meantime pamphlet copies of both the Constitution and By-laws are available and may be obtained, without charge, by any member of the Institute upon application to Institute headquarters in New York.

F. L. HUTCHINSON, National Secretary.

Corona Investigation on an Artificial Line

BY MURRAY F. GARDNER*
Associate A. I. E. E.

Synopsis—*Accompanying corona on a transmission line, there has been found, in several cases, an appreciable increase in the line charging current over that indicated by the usual formula. This has been taken to indicate an increased line capacitance resulting from the presence of the corona envelope about the conductors, and has, for this reason, come to be described as the extra-capacity effect of corona. This explanation, by an envelope, however, has not been entirely satisfactory, and the question has arisen as to whether the current increase could not have been equally as well attributed to the current and voltage harmonics which the corona introduces.*

The paper describes an investigation made of this extra-capacity effect on an artificial transmission line using artificial corona. In avoiding, by means of this method, the glow discharge of real corona, all envelope effects were eliminated. The operation of the artificial corona is described, and the results given of the tests which were made in checking its characteristics against those of real corona.

By means of the artificial corona is shown that it is possible to obtain the extra-capacity effect of corona without having present an ionized envelope. The explanation is offered that at least the larger portion of this effect found on transmission lines under corona conditions is apparent only; that it is a result of the approximate method by which the line capacitance is calculated, and the increased admittance which the line offers to currents of harmonic frequencies.

The effect of corona leakage in altering potential rise on an open line is shown by representative voltage distribution curves taken on an artificial line with and without the corona leaks operating. From a comparison of these curves it appears that the leakage of corona plays a predominant part in the establishment of the resultant voltage, the harmonics caused by the corona in no case producing unusual resonance effects or extra-potential rises. This is important largely for the indication it gives that the present methods of predetermining voltage distribution on open lines for corona conditions are accurate within the limits of engineering accuracy.

Qualitative results are given showing the effectiveness of corona leakage in reducing traveling waves such as result from switching operations. Two oscillograms of the same transient are shown, one taken with the corona leaks operating and the other without. The much shorter duration of the transient in the former case is evidence of the corona's effectiveness in absorbing the energy of the disturbance.

Introduction

UNDER ordinary conditions air is a good insulator, but it loses this quality when subjected to an excessive potential gradient, such as occurs near the surface of the conductors of a transmission line when the voltage between lines is increased above a limiting value. In this region of maximum stress, ionization takes place and there is formed about each conductor an envelope of semi-conducting and luminous air, called corona. This envelope is believed to relieve the concentration of stress by increasing the effective diameter of the conductors.

There is a minimum corona-forming voltage, e_0, for every line, dependent upon the configuration of its conductors and the atmospheric conditions under which it operates. With an alternating voltage, the maximum value must exceed this critical voltage before corona forms. If much in excess, the corona starts at e_0 on the increasing portion of each half-voltage wave, and continues until a slightly lower value is reached on the decreasing portion. Corona under these conditions is pulsating, its frequency being double that of the voltage. This pulsation causes a cyclic change in line admittance which introduces harmonics, particularly the third.[1]

Accompanying corona, there is a power loss which increases with the square of the excess voltage over the critical value. This is expressed by the formula[2]

$$p = c^2 \left(e - e_0 \right)^2$$

where p is in watts, c is a constant, e is the applied voltage, and e_0 is the disruptive critical value for the line This quadratic law holds except in the neighborhood of e_0, where varied results are obtained due to surface irregularities on the conductors.

Due to corona loss it has been customary to operate lines well below their corona-forming voltage. But with the large blocks of power now transmitted, it becomes feasible, with certain systems, to raise the operating voltage practically to the corona limit. In seasons of unfavorable weather it is to be expected, therefore, that portions of these systems will operate for considerable periods in a state of corona.

This continual presence of corona, in addition to causing high energy loss, may be a source of serious interference between the transmission line and neighboring communication circuits. The corona introduces an appreciable third harmonic, and this is within the range of audibility in the case of a 60-cycle current. If the power system is three-phase and has its transformers connected in grounded-Y, these triple-frequency currents can flow through the three lines in parallel, combine in phase in the neutral, and complete their circuit through the ground. This induces troublesome voltage disturbances in paralleling telephone and telegraph lines. If the power system does not have a grounded neutral, it is impossible for the third-harmonic currents to flow. To compensate for this, a third-harmonic voltage appears between each line and neutral.[1] These voltages, being in phase, cause the whole system to pulsate with a triple frequency to ground. This pulsation induces a voltage between lines and ground in the paralleling circuit which even transposition will not eliminate. It appears, therefore, that interference due to corona harmonics presents a serious problem in any extensive operation above the corona-forming voltage.

*Massachusetts Institute of Technology.

1. F. W. Peeks, Jr., "Voltage and Current Harmonics Caused by Corona," TRANS. A. I. E. E., 1921, p. 1155.

2. F. W. Peek, Jr., "Dielectric Phenomena in High-Voltage Engineering," 1920, p. 122.

This paper was awarded the "First Paper Prize" of the Institute for the year 1924. Presented at the Boston Section Meeting of the A. I. E. E., March 4, 1924.

On the other hand, the presence or ready formation of corona may be of some advantage. It may assist in damping high-voltage transients.[3] When operating near the corona limit, the rapidly increasing energy loss for slight rises in potential above normal is likely to be of considerable value in absorbing and quickly attenuating these disturbances. Corona's real effectiveness in this respect, however, has not been definitely determined.

The leakage effect of corona may also be of assistance in keeping down the magnitude of potential rise at the open end of a long line should the line accidentally become open-circuited. This reducing effect would be desirable, as the rise subjects the insulators to high potential strains, and causes the line to draw an excessive charging current from the connected generators.

A further interesting feature of corona is the discrepancy found between the measured charging current for a line and that indicated by the usual formula, when voltages are used which are above the critical corona value.[4] As the line potential is raised from low values up to e_0, the charging current increased proportionately. Slightly above, as corona forms, the current diverges from the linear relation; and for higher voltages, rises much more than proportionately. Since this is the same result as would be obtained were the line capacitance to increase above normal at these high voltages, the divergence has come to be described as the extra-capacity effect due to corona.

There are several explanations of this non-linear increase of current. Usually it is explained by assuming the line capacitance to be increased due to a cyclic change in effective conductor diameter caused by the corona. To account for the total test charging current in this way, however, requires in some cases an effective conductor of from fifty to eighty times normal diameter.

This explanation is also open to question due to the fact that it assumes that, were the capacitance to remain normal under corona conditions, the charging current would continue to rise linearly with the voltage. It is believed that the current might rise above the linear relation even with a normal capacitance, because of the corona harmonics. From this standpoint, it would seem more likely that the increase is the result:

1. Of the very approximate method by which the capacitance current is calculated.

2. Of the increase in admittance which the line, like any other circuit of relatively high capacitance, offers to currents of harmonic frequencies.

In these two explanations there is involved no action of the corona envelope, the current increase being considered the result solely of harmonics.

3. F. W. Peek, Jr., "The Effect of Transient Voltages on Dielectrics," Journ. A. I. E. E., June 1923, p. 623.

4. W. W. Lewis, "Some Transmission Line Tests," Trans. A. I. E. E., 1921, p. 1079.

F. W. Peek, Jr., "Voltage and Current Harmonics Caused by Corona," Trans. A. I. E. E., 1921, p. 1155.

Purpose

The purpose of this paper is to present the results of an investigation carried on in the Research Division of the Electrical Engineering Department, Massachusetts Institute of Technology, aimed at the representation of corona effects on artificial lines. It describes the artificial corona which was developed, and gives the results of tests in which it was used. The latter tests were for the purpose of: First, obtaining experimental evidence in support of the "harmonic" explanations for the increased charging current which accompanies corona. Second, determining the effect of corona in altering voltage distribution and third, investigating its effectiveness in reducing traveling waves in the system.

Development of an Artificial Corona

As evidence was sought to show that the increased charging current is the result of harmonics rather than of the corona envelope, it was necessary to have a check upon the envelope effect. This being practically impossible with real corona, the envelope was eliminated from consideration by simulating the corona effects artificially on an artificial line.

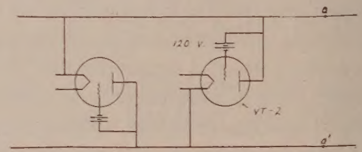


Fig. 1—Connections of Artificial Corona Leak

The artificial corona consisted of a representation of the cyclic change in line leakage peculiar to corona. The leakage variation was obtained by the use of three-electrode vacuum tubes, the current characteristics of which are in many respects similar to those of ionized air. As the tubes pass current only in one direction, two were necessary for one complete leak—one to operate on the positive half of the voltage cycle and the other on the negative half. Fig. 1 shows the interconnection used.

The operation of the leak depended upon the non-linear characteristics of the tubes. The filament of the first tube and the grid and plate of the second connected to one line wire, while the filament of the second and the grid and plate of the first connected to the other line wire. The breakdown voltage, that is, the e_0 of the leak, was governed by a bias potential of approximately 120 volts in each grid circuit. This, with the type of tube used ($V\ T$-2), kept the grid negative and the tube inactive until 115 volts, instantaneous between line wires, was reached on the ascending portion of the wave. With a plate potential of 115 volts and the grid 5 volts negative, conditions were favorable for the passage between line wires of a small plate current through one tube. As the maximum rose above 115 volts, the grid of this tube became less negative and finally positive, while its plate potential steadily

increased. This resulted in a rapidly increasing leakage current up to the crest of the voltage; beyond, on the descending portion of the wave, the action was reversed. The leak was then inactive until the second tube repeated the cycle under the negative voltage loop.

The leak may be likened to a two-way valve, in that it permitted leakage only for the intervals during which the instantaneous values of the voltage wave exceeded its breakdown value, e_0. It gave a small, discontinuous leakage current, Fig. 2, which was zero at all time except

Fig. 2—Discontinuous Leakage Current given by the Artificial Corona Leak

under the crests of the voltage wave. The shape and amount of this current could be controlled by adjustment of filament temperature and bias potential. By increasing the latter, the breakdown voltage was increased, and the leakage reduced. If the breakdown voltage had been established, the amount of the leakage could be controlled by the filament temperature. As used in the following tests the r. m. s. critical voltage, e_0, for the leaks was approximately 75 to 80 volts, representing $\frac{115}{\sqrt{2}}$ volts.

By shunting the terminals of the leak with a small paper condenser at $a\, a'$ in Fig. 1, the distorted current

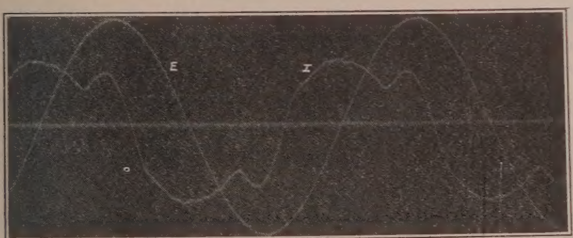


Fig. 3—Current Obtained with Artificial Corona Leak and Condenser in Parallel

shown in Fig. 3 was obtained. As a voltage greater than e_0 was applied, there was a leakage current in addition to a charging current, the leakage current causing a hump on the latter slightly in advance of each voltage crest. The smaller irregularities in the current were due to tooth harmonics in the voltage wave. In later tests these were eliminated by the use of filters.

That the leakage current of the artificial corona was similar to that of real corona may be observed by comparing Figs. 2 and 3 with the wave forms obtained of the latter by Whitehead[5] and by Bennett.[6] In both of

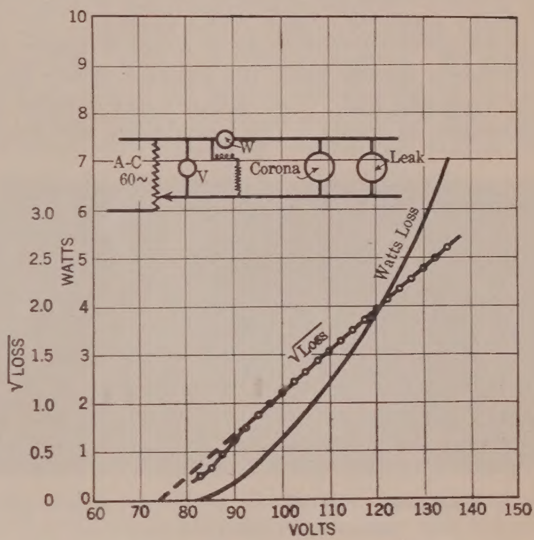


Fig. 4—Curve Showing that the Artificial Corona Leak Satisfies the Quadratic Law of Corona Loss

these cases, the real corona was formed on a rod within a concentric cylinder. The oscillograms of Bennett show the distortion caused by corona of the rod-and-cylinder capacitance current when the applied voltage exceeded the critical corona-forming value for the apparatus. The corona introduced a hump into the charging-current wave just in advance of each voltage crest. In the duplication of this, with the artificial

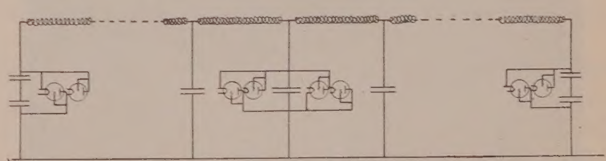


Fig. 5—Connection of Corona Leaks to the Artificial Line

corona, the capacity effect of the rod and cylinder was supplied by the small fixed condenser shunting the leak terminals. The wave forms reported by Whitehead were obtained by a separation of the total current, as found by Bennett, into two parts—a charging current and a corona current. For this the current wave was taken, first below and then above the critical voltage, the difference between the two giving the wave form of the corona current. This latter was pulsating. Its

5. Whitehead and Inouge, "Wave Form and Amplification of Corona Discharge," Trans. A. I. E. E., 1922, p. 138.

6. E. Bennett, "An Oscillograph Study of Corona," Trans. A. I. E. E., 1913, p. 1787.

humps were asymmetrical, but they attained their maximums approximately under the crests of the voltage.

The conformance of the artificial corona to the quadratic law of corona loss is shown by the typical power-loss curve given by a single leak. (Fig. 4.) The test for this type of curve consists of a plot of square root of the power against volts, the points of which should lie on a straight line. The leakage curve satisfied this requirement, as shown. The straight-line plot may be

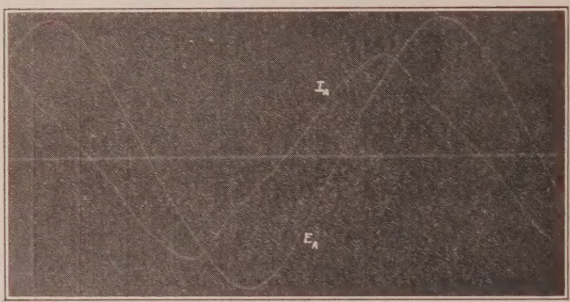


Fig. 6—Charging Current for an Artificial Line having Artificial Corona Leaks

compared favorably with similar plots given by Peek.[7] It is interesting to recall, in this connection, that the deviation from the theoretical curve in the region of e_0 is also a characteristic of real corona.

The artificial line to which the corona leaks were attached represented a single-phase line having 500,000-cir. mil conductors, spaced 9 ft. between centers.[8] One leak was placed at each end and two leaks in parallel at the middle. This was in accordance with the pi-

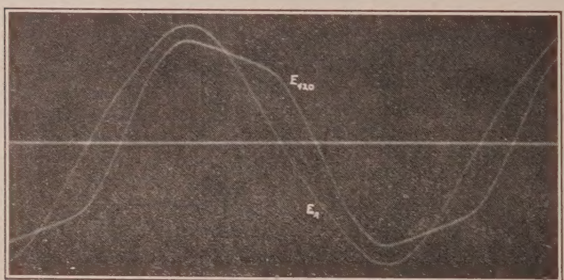


Fig. 7—Voltage Wave Forms at the Two Ends of a 420-Mile Line with Corona Leaks Operating

construction of the line, and gave twice the leakage at the middle as at the ends. See Fig. 5. The critical voltage, e_0, for the line was established at 81 volts.

Using a 420-mile length of open line, oscillograms were taken of voltage and charging current at the generator end, both with and without the leaks operating. When they were attached, but inoperative, (filament currents zero), the current and voltage were normal sine waves. When placed in operation, they caused the distortion shown in Fig. 6. Analysis of the wave forms of the latter showed the voltage to have a three per cent third harmonic; and the current to have a nine per cent third harmonic, three per cent fifth harmonic, and one and three-tenths per cent seventh harmonic. These compare favorably with the voltage and corona-plus-capacity-current wave forms at the generator end of a real transmission line under corona conditions, as given by Peek.[9]

By these preliminary experiments the characteristics of the artificial corona were checked against those of real corona. It was shown that the leakage current

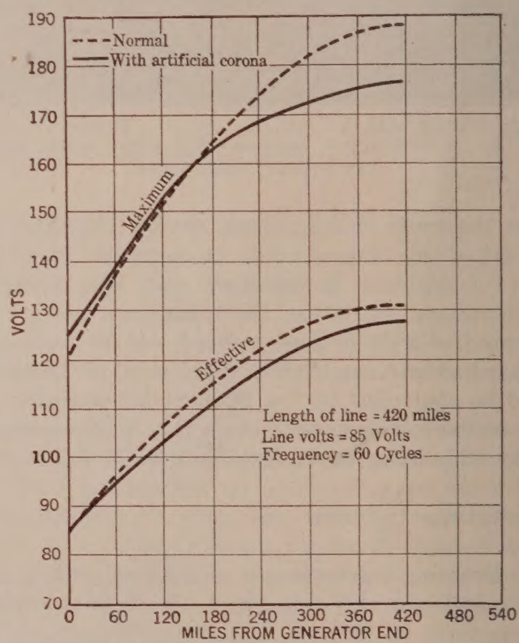


Fig. 8—Crest and R. M. S. Voltage Distribution on 420-Mile Line, with and without the Artificial Corona

was of approximately correct wave form, and that the power loss varied with the voltage in agreement with the quadratic law. Further, when operating on the artificial line, the distortion produced in the voltage and current was similar to that found with real corona on a real line.

Distortion of Voltage

Oscillograms were now taken of voltage wave forms at points out along an open line. The use of a vacuum-tube repeater[10] made it possible to attach the oscillograph to the unloaded line without disturbing voltage

7. F. W. Peek, Jr., "Dielectric Phenomena in High-Voltage Engineering," 1920, p. 128.

8. A. E. Kennelly, "Artificial Electric Lines," 1917, pp. 205-7. Kennelly and Nabeshima, "The Transient Process of Establishing a Steadily Alternating Current on a Long Line," *Pro. Am. Phil. Soc.*, 1920, p. 325.

9. F. W. Peek, Jr., "Dielectric Phenomena in High-Voltage Engineering," 1920, p. 118.

10. F. S. Dellenbaugh, Jr., "*Artificial Transmission Lines with Distributed Constants*," Journ. A. I. E. E., Dec. 1923, p. 1293.

conditions. When the leaks were inoperative there was no distortion at any point on the line. But when they were placed in operation, they produced the distortion shown in Fig. 7. Only the two end voltages are given, as they represent the extreme conditions. Analysis of all the waves of the series was made, however, and it was found that the distortion was progressive. It consisted almost entirely of a third harmonic, the magnitude of which increased steadily from four to fourteen per cent between generator and open end.

Using a vacuum-tube, crest-reading voltmeter (also arranged to take negligible power), the maximum voltage values at positions along the line were found in similar manner. Under corona conditions the crest value was increased near the generator end, but decreased near the free end, as shown in Fig. 8.

This progressive increase in voltage distortion is due to the difference in resonance conditions for the fundamental, and for the various harmonics. The latter, as a result, become a larger percentage of the resultant voltage at the distant points.

This distortion of the voltage along a single-phase line is of interest, since it occurred under conditions which provided a circuit for third-harmonic currents. A three-phase line with grounded neutral is equivalent to three such single-phase lines in parallel. The results indicate, therefore, that even with a grounded-neutral system there can be a distortion of voltage between each line and ground. It is of interest also in connection with the explanation given later of the charging current which is found under corona conditions.

Any alteration in maximum voltage values, such as was found, would have an appreciable effect upon the distribution of corona loss, increasing it at the near end and decreasing it at the far end of the line.

Effect of Corona Leakage on Voltage Distribution

An excessive potential rise on an open line under corona conditions has been reported.[4] This has raised questions regarding the effect of corona in altering voltage distribution in cases of open circuit, and the possibilities of serious resonant voltages at triple frequencies.

These points were investigated with the artificial corona. Voltage distribution curves were taken with an electrostatic voltmeter over a wide range of line lengths and voltages, with and without the corona leaks operating. The curves shown in Fig. 8 are typical of the alteration in distribution found in every case. To this, even a 240-mile line proved no exception. This is important as this line represented approximately a quarter-wave length for the third harmonic of sixty cycles—a condition which would be most favorable for the formation of high-resonant voltages by the corona if resonance effects of the harmonics should prove to be present.

In these tests it was found that the normal voltage distribution, that is, for no corona leakage, held also for corona conditions unless the applied voltage was excessively high or the length of line extreme. With a long line and an applied voltage near the critical value, the distribution was appreciably lowered. It appears, therefore, that in the case of distributions on long lines the reducing effect of corona as a leakage will largely overbalance any tendencies toward high voltage resonance due to the harmonics it may introduce.

In making voltage distribution computations for high-voltage lines where corona must be considered, it has been customary to represent the probable corona loss by an equivalent ohmic leakance. In this, the assumption has been made that corona would tend as a leakage to reduce the rise of potential should the line accidentally become open-circuited. The above results appear to substantiate this assumption. Further, it was possible in the case of each of the tests on the artificial line to calculate a distribution which would agree within the limits of engineering accuracy with the distribution obtained by test. For this the usual hyperbolic formulas were employed, using a leakance, g, obtained from the division of measured loss by the average of the squares of the end voltages.

For all these tests it was possible to check the adequacy of the corona representation. The critical corona voltage of the single-phase power line, which the artificial line represents,* is approximately 95.2 kv. to neutral, assumptions being made as to atmospheric conditions and state of conductor surface.[11] As this corona-forming voltage was represented on the artificial line by 81 volts, the ratio between corresponding line voltages was $\frac{81}{95,200}$. It was thus possible to check the corona representation, as the corresponding losses on the artificial line and on the real line were to be to each other as the square of this voltage ratio. In all cases the loss measured was found to be within 10 per cent of the loss which was calculated for the condition by this method.

Effectiveness of Corona in Damping Transients

Tests were also made to show the possible effectiveness of corona in attenuating traveling waves, such as result from switching operations in the system. For this a single-phase artificial line with distributed constants was used. It represented 331 miles of No. 00 solid copper conductors having 8 ft. 9 in. spacing.[10]

4. loc. cit.

*See page 816.

11. F. W. Peek, Jr., "Dielectric Phenomena in High-Voltage Engineering," 1920, p. 203.

10. loc. cit.

A synchronous switch closed the circuit between generator and line at any desired point on the voltage wave. Two oscillograms for each point of switch-closing were taken—one to show the transient under normal conditions, and the other the same transient with corona present. Their difference represented the modification resulting from the corona leakage.

In Figs. 9 and 10 are given typical transients for the two cases. They show the generator voltage and the current entering the open line when the switch was closed on the descending portion of the voltage wave. In the first, without corona, the deviation from the sinusoidal state is apparent for approximately two

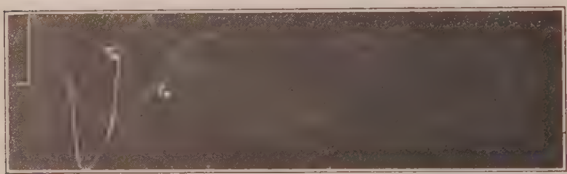


Fig. 9—Current Transient on Open Line without Corona Switch Closed 115 deg. After Voltage Passed Through Zero

cycles, and six reflections are distinguishable. In the second, taken with corona present, the steady-state condition was reached in half a cycle. In this latter, the normal distortion of the current due to the corona should not be confused with the transient.

Although these last results are only qualitative, they support the general belief that corona, as a leakage occurring with excessive voltage, acts to suppress abnormal voltage disturbances. In functioning as a

Fig. 10—Current Transient as Shown in Fig. 9, but with Corona

safety valve, it serves to dissipate the excess energy of the traveling waves and reduce them rapidly to the steady-state condition.

Effect of Harmonics on Apparent Capacitance

In corona loss tests on transmission lines, readings are taken of current, voltage and power. From the ratio of watts to volt-amperes the power factor is calculated, and thereby the line current resolved into two components—one in phase with the voltage, and the other at right angles and leading. The latter, (considered the charging current for the line capacitance) increases linearly with the voltage up to the point of corona formation; beyond, it bends rapidly upward. Curves showing this are given by Lewis[4] and Peek. The variation from the linear relation above the critical voltage is generally attributed to the presence of the corona envelope increasing the line capacitance.

This feature of corona was investigated on the artificial line. Corona loss tests were made, and essentially the same procedure followed in measurement and calculation as outlined above. For each voltage the value of line capacitance corresponding to the quadrature current was computed. The results, given in

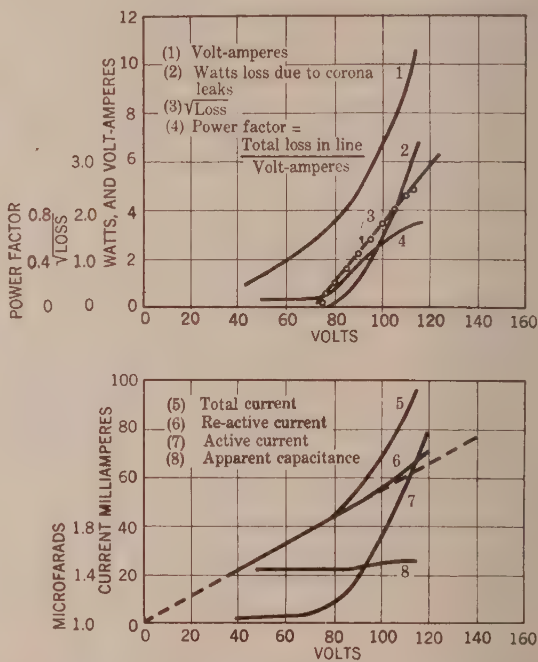


Fig. 11—Characteristic Corona Curves Obtained on an Artificial Line having Artificial Corona, Showing Typical Increase in Line Capacitance

graph form in Fig. 11, show in the upper part the variation of volt-amperes, net watts of corona loss, and power factor with applied voltage. In the lower part are given the total current, corona current, charging current, and the apparent capacitance. There is an interesting similarity between these and the characteristic curves of real corona.

The true capacitance of the 189 miles of artificial line was 1.445 microfarads. The capacitance calculated to agree with the test charging current at a voltage 40 per cent above the critical value was 1.51 microfarads. Thus with only the leakage effect of corona represented, the capacitance of the line was apparently increased 4.6 per cent, and this with no actual change taking place in the fixed condensers which supplied it. In this connection, Lewis reports an increase of 32 per cent, found when the voltage was 70 per cent above the critical

value. Although small in comparison with this, the increase which was obtained on the artificial line showed plainly that an ionized envelope is not an essential to the occurrence of this effect.

It was possible to show in another way that at least much of this capacitance change found on lines is apparent. The above test was repeated, measuring only the loss in a single corona leak shunted by a fixed condenser. The quantities, Fig. 12, were calculated as for a line. The curves are almost exact duplications in form of those given for real corona. The charging current and apparent capacitance of the condenser were distinctly increased at voltages exceeding the critical value of the leak. The capacitance changed from 1.06 to 1.25 microfarads, which is a 21 per cent increase for a

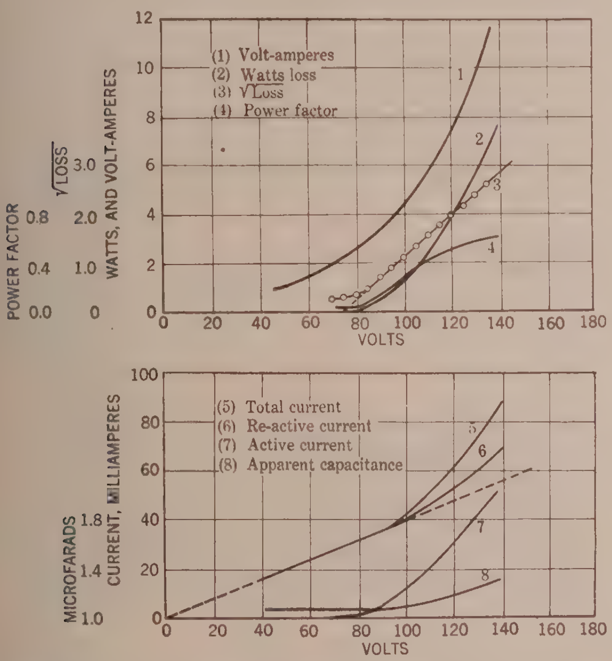


FIG. 12—CHARACTERISTIC CORONA CURVES OBTAINED WITH AN ARTIFICIAL CORONA LEAK SHUNTED BY A FIXED CONDENSER, SHOWING APPARENT INCREASE OF CAPACITANCE

voltage 67 per cent above the critical value. These results were obtained, using a voltage of approximately 100 volts; there was no corona envelope, and the true capacitance of the circuit was known to remain constant, being a fixed condenser.

In both of these tests the increase in charging current was *real*, but the increase in capacitance only *apparent*. This may be explained by the presence of harmonics.

In the transmission line case there was a distinct distortion of the voltage between line and ground out along the line due to the corona harmonics. (Shown in Fig. 7). Being impressed on the normal line capacitance, these harmonic voltages produce large charging currents due to the fact there is an increased susceptance to currents of harmonic frequencies. The result is that the quadrature, or capacitance component of the line current is increased more than proportionately to the applied voltage.

Further, as shown in Fig. 6, the current at the generator end of the line under corona conditions was highly distorted in comparison with the voltage at that point. The meters connected there for measuring the current and voltage indicated only the effective values of the wave forms, and in making the subsequent computations, equivalent sine waves having these values were substituted for the distorted waves.

The error introduced by neglecting the harmonics in making the calculations is brought out by the results of the test on the leak and shunting condenser. In that case the current and voltage wave forms were as shown in Fig. 3; the current only was distorted, the voltage remaining practically sinusoidal. This produced a decrease in the power factor for the harmonics which existed in the current and not in the voltage contributed nothing to the average power, but did increase the effective value of the current required to produce that power. The result of this is shown by the vector diagram of Fig. 13.

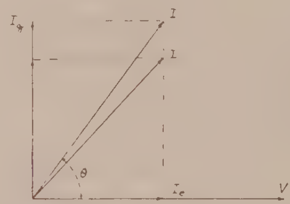


FIG. 13—ILLUSTRATING HOW INCREASE IN CAPACITANCE RESULTS FROM THE SUBSTITUTION OF EQUIVALENT SINE WAVES

The fundamental I_1 of the current has an energy component I_e in phase with the voltage, V. As the voltage is sinusoidal, this is the only part of the current that contributes to the power. The harmonics increase the effective value of the total current from I_1 to I, but its energy component must remain the same. Consequently, when an equivalent sine wave is used for I, as is done in making the usual computations, the result is an increased quadrature current I_q, and corresponding apparent capacitance calculated from $C = \frac{I_q}{\omega V}$.

The results of the above tests are evidence that the capacitance change attributed to corona is not at least entirely a phenomenon due to the presence of an envelope. The indications are that it is a direct result of distorted wave forms, and of a method of calculation in which only equivalent sine waves are considered. The "change in capacitance" accompanying corona is a means of describing a particular effect, that is, the upward bend of the charging current, and its explanation therefore is largely a matter of definition. Although capacitance is usually defined as the charge per

unit rise of potential, it is not likely that the ions of the corona envelope constitute a charge in the true sense of the word, as probably little of the charge in the envelope can return to the conductor as the voltage drops from its crest value.

The final proof of whether or not there is a real capacitance change may well lie in the actual measurement of a line capacitance both with, and without, corona present. Tests of this nature have been made at Massachusetts Institute of Technology by M. T. Dow. An exploring wire was placed in the field near one of the conductors of a laboratory span, upon which was formed direct-current corona, and the capacitance between the wire and conductor measured. This is a method laden with experimental difficulties due to the high voltages which must be used, the smallness at best of the quantities dealt with, and the essentially negative nature of the problem. Four different methods of capacitance determination were used, but no indications of any capacitance increase were found. This warrants the conclusion that the increase, if there is any due to the corona envelope, is very small. There seems, therefore, to be as yet no definite proof that corona does cause an actual change in the capacitance of a transmission line.

SUMMARY

1. The energy loss and distortion characteristics of corona can be closely approximated on an artificial line by simulating the cyclic change in line leakance peculiar to corona. This corona leakage can be lumped similarly to the resistance, capacitance and inductance of the line.

2. Corona may cause a distortion of voltage to neutral even when there is a complete circuit for the third-harmonic currents provided by a grounded neutral.

3. The harmonics introduced by corona will not cause unusual resonance effects or extra-potential rises in the case of an unloaded line.

4. The results indicate that voltage distribution for usual corona conditions can be calculated within engineering accuracy by the methods at present in use. For this, the corona loss can be represented by an equivalent ohmic leakance.

5. Qualitative results were obtained which support the general belief that corona, in forming only at high voltages, can be effective in suppressing high-voltage disturbances.

6. The "extra-capacity effect" accompanying corona is largely a matter of definition. The presence of an envelope of ionized air about the conductors is not an essential to its occurrence. It is probable that at least the greater part of the capacitance change is apparent only, resulting from the method by which the capacitance is calculated, and from the increased line admittance to charging currents of harmonic frequencies.

In conclusion, the author wishes to thank Doctor V. Bush for suggesting and supervising this investigation, and also Messrs. M. T. Dow and R. Henriksen for their assistance in the experimental work.

ROCKY MOUNTAIN LIGHTNING

A condition of the insulation of transmission lines is described as follows. The condition may be designated as a small insulator and high insulation.

The transmission system is for the Western Colorado Power Company. The general location is Southwestern Colorado. The altitudes considered range from six thousand feet to thirteen thousand feet, and the description is given particularly to show how the local atmospheric conditions differ from the humid atmosphere of other districts at lower altitudes, where lightning storms are prevalent.

To understand the effects of lightning in the Rocky Mountains, a knowledge of the insulation afforded by the presence of a dry atmosphere is necessary.

A wooden pole line, four miles in length, using pony-glass insulators on wooden pins, was built with the usual construction for twenty-three hundred volts. The line was operated for some time at twenty-three hundred volts, but lightning troubles caused several interruptions.

Without changing the glass insulators or other conditions on the pole line, the circuit voltage was raised to seventeen thousand volts. The lightning troubles in the station decreased immediately, and the line has operated for fourteen years without burning off a cross-arm.

Troubles at the transformers decreased because seventeen thousand-volt bushings are of higher insulation than twenty-three hundred-volt bushings and transformers.

Another experience—On the seventeen-thousand-volt lines radiating from Silverton, a line wire will occasionally be torn loose from the insulator and drop down on the wooden cross-arm. The electric service will be continued as usual. Days and even weeks may pass before a patrolman discovers the bare wire resting harmlessly on the wooden cross-arm, but in a humid climate a 2300-volt wire in the same position will burn the cross-arm completely off.—JOHN A. CLAY.

NEW SPECTACLES AND COLOR MATCHING

No longer need a clothing store salesman take a suit to the window to show the prospective customer the effect in daylight, or even turn on a special light. Instead, he will soon be able to hand the customer a pair of day-light spectacles which have been invented by Dr. Hermann Weiss of Vienna. Already they have come into wide use in laboratories in the textile, paper and dye industries, where it is often necessary to judge the color of solutions. They are of blue glass which absorbs some of the yellow rays in which the ordinary incandescent lamp is rich but which are not present in such abundance in sunlight.

The Loaded Submarine Telegraph Cable

BY OLIVER E. BUCKLEY[1]
Member, A. I. E. E.

***Synopsis.**—With an increase of traffic carrying capacity of 300 per cent over that of corresponding cables of the previous art, the New York-Azores permalloy-loaded cable marks a revolution in submarine cable practise. This cable represents the first practical application of inductive loading to transoceanic cables. The copper conductor of the cable is surrounded by a thin layer of the new magnetic material, permalloy, which serves to increase its inductance and consequently its ability to transmit a rapid succession of telegraph signals.*

This paper explains the part played by loading in the operation of a cable of the new type and discusses some of the problems which were involved in the development leading up to the first commercial installation. Particular attention is given to those features of the transmission problem wherein a practical cable differs from the ideal cable of previous theoretical discussions.

Brief mention is made of means of operating loaded cables and the possible trend of future development.

* * * * *

THE announcement on September 24, 1924, that an operating speed of over 1500 letters per minute had been obtained with the new 2300-mile New York-Azores permalloy-loaded cable of the Western Union Telegraph Company brought to the attention of the public a development which promises to revolutionize the art of submarine cable telegraphy. This announcement was based on the result of the first test of the operation of the new cable. A few weeks later, with an improved adjustment of the terminal apparatus, a speed of over 1900 letters per minute was obtained. Since this speed represents about four times the traffic capacity of an ordinary cable of the same size and length, it is clear that the permalloy-loaded cable marks a new era in transoceanic communication.

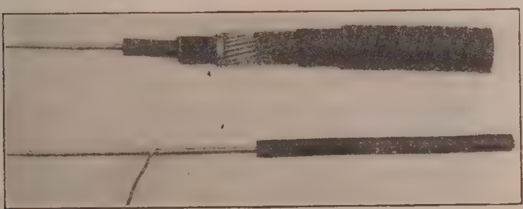


FIG. 1—PERMALLOY-LOADED CABLE

Above, section of deep sea type showing construction.
Below, section of core showing permalloy tape partly unwound.

The New York-Azores cable represents the first practical attempt to secure increased speed of a long submarine telegraph cable by inductive loading and it is the large distributed inductance of this cable which is principally responsible for its remarkable performance. This inductance is secured by surrounding the conductor of the cable with a thin layer of permalloy. Fig. 1 shows the construction of the deep sea section of the cable. In appearance it differs from the ordinary type of cable principally in having a permalloy tape, 0.006 in. thick and 0.125 in. wide, wrapped in a close helix around the stranded copper conductor.

Permalloy, which has been described by Arnold and Elmen[2], is an alloy consisting principally of nickel and iron, characterized by very high permeability at low magnetizing forces. The relative proportion of nickel and iron in permalloy may be varied through a wide range or additional elements as, for example, chromium may be added to secure high resistivity or other desirable properties. On account of its extremely high initial permeability, a thin layer of permalloy wrapped around the copper conductor of a cable greatly increases its inductance even for the smallest currents.

In the case of the New York-Azores cable the permalloy tape is composed of approximately 78½ per cent nickel and 21½ per cent iron and gives the cable an inductance of about 54 millihenries per nautical mile. An approximate value of the initial permeability of the permalloy in that cable may be obtained by assuming the helical tape replaced by a continuous cylinder of magnetic material of the same thickness. This material would have to have a permeability of about 2300[3] to give the observed inductance. A better appreciation of the extraordinary properties of the new loading material may be obtained by comparing this permeability with that which has previously been obtained with iron as the loading material. The Key West-Havana telephone cables are loaded with 0.008-in. diameter soft iron wire. The permeability of this wire, which was the best which could be obtained commercially when that cable was made, is only about 115, or approximately one-twentieth that of the permalloy tape of the New York-Azores cable.

The proposal to use permalloy loading to increase the

1. Bell Telephone Laboratories, Inc.

Presented at the Annual Convention of the A. I. E. E., Saratoga Springs, June 22-26, 1925.

2. *Journ. Franklin Inst.*, Vol. 195, pp. 621-632, May 1923.

3. The true initial permeability is slightly higher. To compute it, account must be taken of the fact that, contrary to what has been sometimes assumed, the magnetic lines of induction in the tape do not form closed loops around the wire but tend to follow the tape in a helical path. The pitch of the helical path of the lines of induction is slightly less than that of the permalloy tape with the result that a line of induction takes a number of turns around the conductor, then crosses an airgap between two adjacent turns of tape and continues along the tape to a point where it again slips back across an airgap. O. E. Buckley, British Patent No. 206,104, March 27, 1924, also K. W. Wagner, *E. N. T.*, Vol. I, No. 5, p. 157, 1924.

speed of long telegraph cables was one outcome of an investigation undertaken by the author, soon after the war, to determine whether some of the new methods and materials developed primarily for telephony might not find important application to submarine telegraphy. In the subsequent development of the permalloy loaded cable a large number of new problems, both theoretical and practical, had to be solved before the manufacture of a cable for a commercial project could be undertaken with reasonable assurance of success. The problems encountered were of three principal kinds. First was that of the transmission of signals over a cable having the characteristics of the trial conductors made in the laboratory. Although the theory of transmission over a loaded cable had been previously treated by others, the problem considered had been that of an ideal loaded cable with simple assumptions as to its electrical constants and without regard to the practical limitations of a real cable. The second class of problems had to do with the practical aspects of design, manufacture and installation. In this connection an extensive series of experiments was conducted to determine the

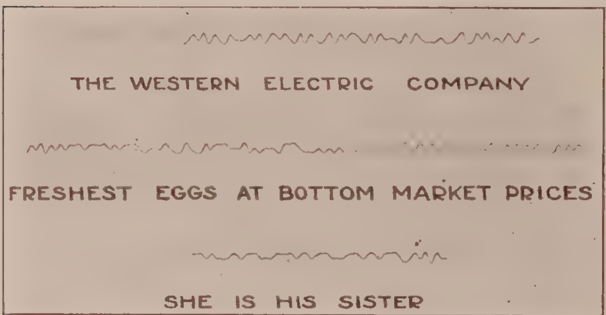


Fig. 2—Test Message—Western Union New York-Azores Permalloy Loaded Cable

Sent from Horta (Azores) and received at New York November 14, 1924.
Speed—1920 letters per minute.
Recorded with special high speed siphon recorder.

means required to secure, at the ocean bottom, the characteristics of the laboratory samples on which the transmission studies were based. Among the numerous problems which arose in this connection were those concerned with protecting the copper conductor from any possible damage in the heat-treating operation which was necessary to secure the desired magnetic characteristics, and those concerned with protecting the strain-sensitive permalloy tape from being damaged by submerging the cable to a great depth. The third class of problem had to do with terminal apparatus and methods of operation. The prospective speed of the new cable was quite beyond the capabilities of standard cable equipment and, accordingly, new apparatus and operating methods suited to the loaded cable had to be worked out. In particular it was necessary to develop and construct instruments which could be used to demonstrate that the speed which had been predicted could actually be secured. The success of the investigations along all three lines is attested by the results which were obtained with the New York-Azores cable. Fig. 2 shows a section of cable recorder slip, the easily legible message of which was sent from Horta, Fayal, and received at New York at a speed of 1920 letters per minute.

It is principally with regard to the first of these classes of problems, that of the transmission of signals, that the following discussion is concerned. No attempt will be made here to discuss the details of design and development of the physical structure of the cable, nor will there be given a detailed description of the operating results or how they were obtained; these subjects must be reserved for later publication. It is desired in what follows to explain how inductive loading improves the operation of a submarine cable and to point out some of the problems concerned with the transmission of signals which had to be considered in engineering the first long loaded cable.

In order to understand the part played by loading in the transmission of signals, it is desirable first to review briefly the status of the cable art prior to the introduction of loading and to consider the factors then limiting cable speed and the possible means of overcoming them. A cable of the ordinary type, without loading, is essentially, so far as its electrical properties are concerned, a resistance with a capacity to earth distributed along its length. Although it does have some inductance, this is too small to affect transmission at ordinary speeds of operation except on cables with extremely heavy conductors. The operating speed of a non-loaded cable is approximately inversely proportional to the product of the total resistance by the total capacity; that is,

$$S = \frac{k}{C R l^2}$$

where C is capacity and R resistance per unit length, and l is the length of the cable. The coefficient, k, is generally referred to as the speed constant. It is, of course, not a constant since it depends on such factors as terminal interference and method of operation, but is a convenient basis for comparing the efficiency of operation of cables of different electrical dimensions. As the technique of operating cables has improved, the accepted value of k has increased, its value, at any time, being dependent on the factor then limiting the maximum speed obtainable. This factor has, at times, been the sensitiveness of the receiving apparatus, at other times, the distortion of signals and in recent years, interference. During a great part of the history of submarine cable telegraphy, distortion was considered the factor which limited the speed of operation of long cables and on this account most of the previous discussions of submarine cable transmission have been concerned principally with distortion and means for correcting it. As terminal apparatus was gradually

improved, means of correcting distortion were developed which practically eliminated distortion as an important factor in the operation of long cables. With distortion thus eliminated, the speed was found to be limited principally by the sensitiveness of the receiving apparatus. This limit was, however, in turn eliminated by the development of signal magnifiers. During recent years, in which numerous cable signal magnifiers have been available and methods of correcting distortion have been understood, the only factor limiting cable speed has been the mutilation of the feeble received signals by interference. Most cables are operated duplex, and in these, the speed is usually limited by interference between the outgoing and incoming signals. In cables operated simplex, and also in cables operated duplex where terminal conditions are unfavorable, speed is limited by extraneous interference which may be from natural or man-made sources and which varies greatly in different locations. The strength of the received current must, in either case, be great enough to make the signals legible through the superposed interference current. Owing to the

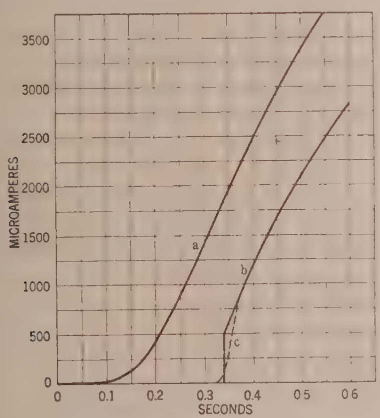


Fig. 3—Arrival Curves

a. Non-loaded cable
b. Ideal loaded cable
c. Real loaded cable (approximate)

rapidity with which the received signal amplitude is decreased as the speed of sending is increased, the limiting speed is quite sharply defined by the interference to which the cable is subject.

With the speed of operation thus limited, there were two ways in which the limiting speed could be increased: the interference could be reduced, or the strength of signals made greater. No great reduction in interference due to lack of perfect duplex balance could be expected, as balancing networks had already been greatly refined. Extraneous interference in certain cases could be reduced by the use of long, properly terminated sea-earths. The signal strength could be increased either by increasing the sending voltage or by decreasing the attenuation of the cable. Nothing at all is gained, however, by increasing the voltage in duplex operation where lack of perfect duplex balance limits the speed, and in simplex operation any gain from raising the voltage is obtained at the cost of increased risk to the cable, the sending voltage being usually limited to about 50 volts by considerations of safety. The attenuation of the cable could be reduced and the strength of the signal increased by use of a larger copper conductor or by using thicker or better insulating material. None of these possible improvements, however, seemed to offer a prospect of very radical advance in the art.

In telephony, both on land and submarine lines, an advantage had been obtained by adding inductance[4] in either of two ways, by coils inserted in series with the line or by wrapping the conductor with a layer of iron. The insertion of coils in a long deep-sea cable was practically prohibited by difficulties of installation and maintenance. Accordingly, only the second method of adding inductance, commonly known as continuous loading, could be considered for a transoceanic telegraph cable and it is primarily with regard to continuous loading that the following discussion is concerned.

Most of the proposals to load telegraph cables have had the object of reducing, or eliminating, distortion, and accordingly most of the mathematical treatments of loading have been from that point of view. The reduction of distortion is, however, not the only benefit to be obtained from loading and, in fact, may not always be secured in the high-speed operation of a loaded cable. The principal benefit of loading from the practical standpoint is to decrease the attenuation of the signals so that for a given frequency more current will be received or so that the minimum permissible current may be received with a greater speed of signaling. From the mathematical standpoint, there are two ways of treating the problem of the loaded

4. The idea of improving the transmission of signals over a line by adding distributed inductance to it originated with Oliver Heaviside in 1887, (*Electrician*, Vol. XIX, p. 79, and *Electromagnetic Theory*, Vol. 1, p. 441, 1893), who was the first to call attention to the part played by inductance in the transmission of current impulses over the cable. He suggested, as a means for obtaining increased inductance, the use of iron as a part of the conductor or of iron dust embedded in the gutta percha insulation. He also proposed inserting inductance coils at intervals in a long line. Other types of coil loading were proposed by S. P. Thompson (British Patent 22,304—1891, and U. S. Patents 571,706 and 571,707—1896), and by C. J. Reed (U. S. Patents 510,612 and 510,613—1893). M. I. Pupin, (A. I. E. E. Trans., Vol. XVI, p. 93, 1899, and Vol. XVII, p. 445, 1900) was the first to formulate the criterion on the basis of which coil loaded telephone cables could be designed. Continuous loading, by means of a longitudinally discontinuous layer of iron covering the conductor, was proposed by J. S. Stone in 1897 (U. S. Patent 578,275). Breisig (*E. T. Z.*, Nov. 30, 1899) suggested the use of an open helix of iron wire wound around the conductor and Krarup (*E. T. Z.*, April 17, 1902) proposed using a closed spiral so that the adjacent turns were in contact. J. H. Cuntz (U. S. Patent 977,713 filed March 29, 1901) proposed another form of continuous loading. Recent general discussion of loaded telegraph cable problems have been given by Malcolm (Theory of Submarine Telegraph and Telephone Cable, London, 1917) and by K. W. Wagner, (E. N. T., Oct. 1924).

cable; first, with regard to the transmission of a transient impulse, and second, with regard to setting up steady alternating currents of definite frequency. In the ultimate analysis the solution of either problem can be got from the other. However, for practical purposes they are two distinct means of attack. Which should be used depends on the object to be secured. If one is concerned primarily with the effect of the cable on the wave shape of the signal transmitted over it, it is fairly obvious that the transient treatment has advantages. If, however, one is concerned only with the strength of the received signal, as is the case if there is assurance that the signal shape can, in any event, be corrected by terminal networks, then the steady state treatment is sufficient and much more convenient to apply. In the case of the real loaded cable the complete transient solution is extremely complex and the steady state treatment relatively simple. The solution of the transient problem of an ideal loaded cable is, however, very valuable to give a physical picture of how inductive loading aids the high speed transmission of signals.

The transient solution of the problem of an ideal heavily loaded cable has been worked out by Malcolm[5] and more rigorously by Carson,[6] who have determined the curve showing the change of current with time at one end of the cable if a steady e. m. f. is applied at zero time between the cable and earth at the distant end. Such a curve is called an "arrival curve" and for an ideal loaded cable comprising only constant distributed resistance, capacity and inductance may have a form like that shown in Curve *b* of Fig. 3, which is to be compared with Curve *a*, which is the arrival curve of a non-loaded cable. The straight, vertical part of Curve *b* represents the "head" of the signal wave which has traveled over the cable at a definite speed and with diminishing amplitude. The definite head of the arrival curve is the most striking characteristic difference between the ideal loaded and the non-loaded cable. In the latter, as is evident from Fig. 3, the current at the receiving end starts to rise slowly almost as soon as the key is closed at the transmitting end. When an e. m. f. is applied to the sending end of the non-loaded cable, a charge spreads out rapidly over the whole length, the receiving end charging up much more slowly than the sending end on account of the resistance of the intervening conductor. Hence, if a signal train, consisting of rapidly alternating positive and negative impulses, is applied to the sending end, the effect at the receiving end of charging the cable positively is wiped out by the succeeding negative charge before there has been time to build up a considerable positive potential and the successive alternating impulses thus tend to annul each other. In the loaded cable the effect of inductance is to oppose the setting up of a current and to maintain it once it has been established, and thus to maintain definite wave front as the signal impulse travels over the cable. Hence, with inductive loading, the strength and individuality of the signal impulses are retained and a much higher speed of signaling is possible. It should be noted that by speed of signaling is meant the rapidity with which successive impulses are sent and not the rate at which they travel over the cable. This speed of travel is actually decreased by the addition of inductance, about one third of a second being required for an impulse to traverse the New York-Azores cable from end to end.

It should be noted that Curve *b* of Fig. 3 is for an ideal loaded cable in which the factors of resistance, capacity and inductance are constant. In a real loaded cable none of these factors are constant and the arrival curve cannot be simply and accurately computed. Even the capacity which is usually assumed as constant for real cables, varies appreciably with frequencies in the telegraph range, and, owing to the fact that gutta percha is not a perfect dielectric material, its conductance, which is also variable with frequency, must be taken into account. Although the inductance of the cable is substantially constant for small currents of low frequency, it is greater for the high currents at the sending end of the cable on account of the increase of magnetic permeability of the loading material with field strength and is less at high frequencies than at low on account of the shielding effect due to eddy currents. The resistance is highly variable since, in addition to the resistance of the copper conductor, it comprises effective resistance due to eddy currents and hysteresis in the loading material, both of which vary with frequency and current amplitude. Furthermore, there is variable inductance and resistance in the return circuit outside the insulated conductor which must be taken into account. Although it is very difficult to compute the exact arrival curve of a cable subject to all of these variable factors, an approximate calculation in a specific case, like that of the New York-Azores cable, shows that the arrival curve has the general shape of Curve *c* of Fig. 3. It will be noticed that although this arrival curve lacks the sharp definite head, characteristic of the ideal loaded cable, it still has a relatively sharp rise and that the time required for the impulse to traverse the cable is not greatly different from that of the ideal loaded cable.

Although it is difficult to take exact account of the variable characteristics of the loaded cable in the solution of the transient problem, it is easy to take account of them in the steady state or periodic analysis by means of well-known methods. If a steady sinusoidal voltage, V_s, is applied at one end of the cable, the resulting voltage, V_r, at the distant end, will be given by the equation

$$V_r = k\, V_s\, \epsilon^{-Pl}$$

where l is the length, P the propagation constant of the cable and k, a constant which depends on the terminal

5. Theory of the Submarine Telegraph and Telephone Cable, London, 1917.

6. TRANS. A. I. E. E., Vol. 38, p. 345, 1919.

impedance and which is unity in case the cable is terminated at the receiving end in its so-called characteristic impedance. The propagation constant is given by the formula,

$$P = \sqrt{(R + i\,p\,L)\,(G + i\,p\,C)} = \alpha + i\,\beta$$

where R is the resistance, L, the inductance, G, the leakance and C, the capacity per unit length and p is 2π times the frequency. The real part of the propagation constant, α, is called the attenuation constant and the imaginary part, β, the wave length constant. By separating α and β, the amplitude and phase displacement of the received voltage relative to the sent voltage may be computed for any particular frequency and the behavior of a complex signal train may be worked out by analyzing it into its Fourier components and treating them separately. The phase shift is, however, of importance mainly as regards the shape of the received signals and their amplitude may, in general, be obtained from the attenuation constant alone. Thus if it is known that the signal shape can, in any case, be corrected by terminal networks, there is no need to be concerned with more than the attenuation constant to compute the speed of the cable.

In the case of a cable of the permalloy-loaded type, α is given with an approximation[7] sufficiently close for the purposes of this discussion by the equation.

$$\alpha = \frac{1}{2}\sqrt{\frac{C}{L}}\left(R + \frac{G}{C}\,L\right)$$

For the purpose of computing R, it is convenient to separate it into its components, giving

$$\alpha = \frac{1}{2}\sqrt{\frac{C}{L}}\left(R_c + R_e + R_s + R_h + \frac{G}{C}\,L\right)$$

where

R_c = copper resistance per unit length
R_e = eddy current resistance per unit length
R_s = sea return resistance per unit length
R_h = hysteresis resistance per unit length

The copper resistance, R_c, is that determined by a direct-current measurement of the loaded conductor, since the resistance of the loading tape is so high and its length is so great that the current flowing longitudinally through it may be safely neglected.

The eddy current resistance, R_e, is given approximately by the formula,

$$R_e = \frac{m\,\mu^2\,t^3\,f^2}{\rho\,(d - t)}$$

where t is the thickness or diameter of the loading tape or wire, d, the outside diameter of the loaded conductor, f, the frequency, ρ, the resistivity of the loading material, μ, its magnetic permeability and m, a constant which depends on the form of the loading material and is, in general, greater for tape than for wire loading. Although it is possible to compute a value of m, the value found in practise is always larger than the theoretical value, which is necessarily based on simple assumptions and does not take into account such a factor as variation of permeability through the cross-section or length of the loading material. Accordingly, it is necessary for any particular type of loaded conductor to determine m experimentally.

The sea-return resistance may safely be neglected in the computation of slow speed non-loaded cables, but it is a factor of great consequence in the behavior of a loaded cable. By sea-return resistance is meant the resistance of the return circuit including the effect of the armor wire and sea water surrounding the core of the cable. Although the exact calculation[8] of this resistance factor is too complex to be discussed here, the necessity of taking it into account may be quite simply explained. Since the cable has a ground return, current must flow outside the core in the same amount as in the conductor. The distribution of the return current is, however, dependent on the structure of the cable as well as on the frequencies involved in signaling. If a direct current is sent through a long cable with the earth as return conductor, the return current spreads out through such a great volume of earth and sea water that the resistance of the return path is negligible. On the other hand, if an alternating current is sent through the cable, the return current tends to concentrate around it, the degree of concentration increasing with the frequency. With the return current thus concentrated the resistance of the sea water is of considerable consequence. It is further augmented by a resistance factor contributed by the cable sheath. This may be better understood by considering the cable as a transformer of which the conductor is the primary and the armor wire and sea water are each closed, secondary circuits. Obviously, the resistances of the secondary circuits of armor wire and sea water enter into the primary circuit and hence serve to increase the attenuation. The presence of the armor wires may thus be an actual detriment to the transmission of signals.

To take account of the hysteresis resistance, R_h, and also of the increased inductance and eddy current resistance at the sending end of the cable, it is most convenient to compute the attenuation of the cable for currents so small that R_h may be safely neglected. The attenuation thus computed is that which would be obtained over the whole cable if a very small sending voltage were used. The additional attenuation at the sending end for the desired sending voltage may then be approximated by computing successively from the sending end the attenuation of short lengths of cable over which the current amplitude may be considered constant, the attenuations of separate lengths being added together to give the attenuation of that part of

7. For accurate computation of attenuation the complete formula for α must be used.

8. See Carson and Gilbert, *Jour. Franklin Inst.*, Vol. 192, p. 705, 1921 and *Electrician*, Vol. 88, p. 499, 1922.

the cable in which hysteresis cannot be neglected. In this computation account must, of course, be taken of the increased inductance and eddy current resistance accompanying the higher currents at the sending end.

Having calculated or obtained by measurement the several resistance factors and knowing the capacity, leakance and inductance, the whole attenuation of a cable for any desired frequency may be computed and a curve drawn showing the variation of received current with frequency for a given sending voltage. This relation for a particular case is shown in Curve *c* of Fig. 4. Curve *a* shows, for comparison, the relation between frequency and received current of a non-loaded cable of the same size, that is, a cable having a conductor diameter the same as that of the loaded conductor and having the same weight of gutta percha. Curve *b* shows the behavior of an ideal loaded cable having the same inductance, capacity and d. c. resistance as the real loaded cable of Curve *c*, but in which the leakance and alternating current increments of resistance are assumed to be zero.

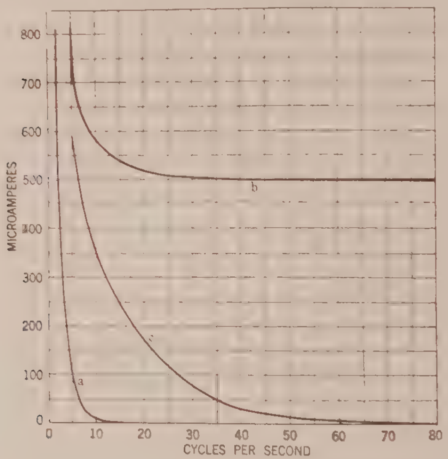


FIG. 4—RECEIVED CURRENT VS. FREQUENCY

a. Non-loaded cable
b. Ideal loaded cable
c. Real loaded cable

Now, if the level of interference through which the current must be received is known, the maximum speed of signaling for the loaded cable may be obtained from Curve *c*. It is that speed at which the highest frequency necessary to make the signals legible is received with sufficient amplitude to safely override the superposed interference. Just what the relation of that frequency is to the speed of signaling cannot be definitely stated, since it depends on the method of operation and code employed as well as on the desired perfection of signal shape. J. W. Milnor[9] has suggested that for cable code operation and siphon recorder reception a fair value is about 1.5 times the fundamental frequency of the signals, that is, the fundamental frequency when a series of alternate dots and dashes is being sent.

By referring again to the equation for α, it can now be explained why high permeability is a necessary characteristic of the loading material if benefit is to be obtained from continuous loading. The addition of the loading material has two oppositely directed effects; on the one hand it tends to improve transmission by increasing the inductance and consequently decreasing the attenuation, and on the other hand it tends to increase the attenuation by increasing the effect of leakance and by the addition of resistance. Not only are the hysteresis and eddy-current factors of resistance added by the loading material, but it must also be looked on as increasing either the copper resistance or the capacity on account of the space it occupies. Generally it is more convenient to look on the loading material as replacing some of the copper conductor in the non-loaded cable with which comparison is made, since by so doing all of the factors outside of the loaded conductor are unchanged. Now, if the loading material is to be of any benefit, the decrease in attenuation due to added inductance must more than offset the increase due to added resistance, including the added copper resistance due to the substitution of loading material for copper. In the limiting case the lowest permeability material which will show a theoretical advantage from this point of view is that which, as applied in a vanishingly thin layer, gives more gain than loss. For any particular size and length of cable there is a limiting value of permeability which will satisfy this condition, this limiting value being greater the longer the cable and the smaller the diameter of its conductor.[10] For transatlantic cables of sizes laid prior to 1923, the minimum initial permeability required to show an advantage is higher than that of any material known prior to the invention of permalloy. Actually a considerably higher permeability than this theoretical minimum was, of course, required to make loading an economic advantage, since there are practical limits to the thickness of loading material and since the cost of applying it has also to be taken into account. Further, there are limits on methods of operation, imposed by loading, which necessitate still higher permeability to make loading worth while.

Since the addition of loading has two opposite tendencies in its effect on attenuation, the practical design of the cable must be based on a compromise between them. Thus, to secure the maximum gain from loading a cable of a given size, the loading material should be chosen of such a thickness that the gain due to increased inductance from a slight increase of thickness just offsets the loss due to increased resistance and dielectric leakance. In practise, of course, economic considerations of the cost of various thicknesses of loading must also be taken into account.

9. JOURNAL A. I. E. E., Vol. 41, p. 118, 1922, TRANSACTIONS A. I. E. E., Vol. 41, p. 20, 1922.

10. O. E. Buckley, British Patent No. 184,774, 1923.

In designing the New York-Azores cable some assumption had to be made as to the extraneous interference which would be encountered. Theoretical considerations led to the belief that the loaded cable would be no more subject to external interference than non-loaded cables. It even appeared that it would be less affected by some types of interference, for, owing to the shorter wave length for a given frequency, a disturbance which affects a great many miles of cable simultaneously is less cumulative in its effect at the terminal of a loaded than a non-loaded cable. A reasonable assumption seemed to be that the total overall attenuation which could be tolerated for the loaded cable was at least as great as that which experience had shown to be permissible for simplex operation of non-loaded cables. Of course, this maximum permissible attenuation depends on conditions of terminal interference, and no fixed value can be given as applicable to all cables. However, for average conditions of terminal interference in locations free from power-line disturbances, and where the cable lies in relatively deep water near to its terminal landing, a reasonable value of total attenuation constant for the fundamental frequency of cable code is about 10 (86.9 T. U.) for recorder operation and about 9 (78.2 T. U.) for relay operation. These were the approximate values assumed for the New York-Azores cable and later experience has demonstrated that they were well justified.

Throughout all of the preceding discourse, it has been assumed that the relation between attenuation and terminal interference would limit the speed of simplex operation rather than that distortion of signal shape would be the limiting factor. Although this is, in fact, the case with non-loaded cables,[11] it was not self-evident as regards the loaded cable, and to make reasonably certain that the speed could be determined from the attenuation-frequency relation required a demonstration that the signal distortion of a real loaded cable could be corrected by suitable terminal apparatus. One of the merits long claimed for loading was that it would reduce distortion and, indeed, an ideal loaded cable with constant inductance and without magnetic hysteresis, eddy current loss, dielectric leakance and sea-return resistance would have very little distortion and would give a speed limited only by terminal apparatus. However, a real loaded cable, the inductance of which varies with both current and frequency and in which all the above noted resistance factors are present, may give, and in general will give when operated at its maximum speed, greater distortion of signals than a non-loaded cable.

To solve the question of distortion on a purely theoretical basis required consideration of the transmission of a transient over the loaded cable. This was made extremely difficult by the existence of numerous possible causes of signal distortion, the effects of which could only be approximated in the solution of the transient problem. In addition to the distortion resulting from the rapid increase of attenuation with frequency due to the various sources of a-c. losses, distortion peculiar to the magnetic characteristics of the loading material had also to be taken into account. There are several types of magnetic distortion worthy of consideration. First, there is the production of harmonics as a result of the non-linear magnetization curve of the loading material; second, there is a possible asymmetrical distortion due to hysteresis, and third, there is a possible modulation resulting from the superposition of one signal upon another, which is, in effect, a modulation of the head of the wave of one impulse by the tail of the wave of a preceding impulse. The first two of these are effective at the sending end of the cable and the third near the receiving end.

A computation of distortion, including the peculiar magnetic effects, by a steady state, a-c. method, based on measurements of short loaded conductors, indicated that the cable should operate satisfactorily with ordinary sending voltages. Further evidence that none of these various types of distortion would be of serious consequence, and that the distortion of a loaded cable could be corrected by terminal apparatus, was obtained by experiments with an artificial line constructed to simulate closely, as regards electrical characteristics, the type of loaded conductor with which experiments were then being made. This artificial line was loaded with iron-dust core coils, which admirably served the purpose, not only as regards inductance and a-c. resistance but also as regards magnetic distortion. Iron dust is, of course, very different from permalloy in its magnetic characteristics. But owing to the large number of turns on a coil, it is operated at much higher field strengths and on a part of the magnetization curve corresponding approximately to that at which permalloy is operated on the cable. In fact the case for magnetic distortion was a little worse on the artificial line than in the then proposed cable. Fig. 5 shows a photograph of the artificial line, the coils of which are in the large iron pots and the resistance and paper-condenser capacity units of which are in the steel cases. This line was equivalent to a 1700-nautical-mile cable, loaded with 30 millihenries per nautical mile, and over it, legible signals were secured at speeds up to more than 2600 letters per min. Such a speed of operation was quite beyond the range of the then available telegraph instruments, and accordingly special transmitting and receiving instruments were required. The multiplex distributor, of the Western Electric printing-telegraph system, proved an excellent transmitter for experimental purposes and, for receiving, use was made of a combined vacuum-tube amplifier and signal-shaping network, the signals being recorded on a string

11. Recent work of J. R. Carson (U. S. Patent 1,315,539—1919) and R. C. Mathes (U. S. Patent 1,311,283—1919) has shown that with the combined use of vacuum tube amplifiers and distortion correcting networks, distortion in non-loaded cables can be compensated to any desired degree.

oscillograph. Fig. 6 shows part of a test message received over the loaded artificial cable at a speed of 2240 letters per min.

The results of the tests with the artificial loaded cable were entirely in agreement with the author's calculations, and showed that it was possible to obtain satisfactory signal shape with a coil loaded cable having a-c. resistance and distortion factors approximating those of the permalloy loaded cable. The exact

Fig. 5—Loaded Artificial Line

behavior of the proposed cable, including such factors as sea-return resistance and a somewhat variable distributed inductance, could not, of course, be duplicated without prohibitive expense. The approximation was considered, however, to be sufficiently good to justify proceeding with a loaded cable installation so far as questions of signal shaping were concerned. It is interesting to note that the factor which limited the operating speed of the artificial loaded cable was one which is not present in a continuously loaded cable but which possibly would be a serious factor in the operation of a coil loaded cable, namely the oscillations[12] resulting from the finite size and separation of the inductance units.

With the completion of the artificial loaded cable tests, there was still one principal question of transmission which had to remain unanswered until a cable had been installed. This was the question of balancing the cable for duplex operation. Ordinary submarine cables are generally operated duplex, the total speed in the two directions being usually from about 1.3 to 2 times the maximum simplex or one-way speed. Except in cases where the external interference is very bad, the limiting speed of duplex operation is determined by the accuracy with which an artificial line can be made the electrical equivalent of the cable. Ordinarily, the artificial line is made up only of units of resistance and capacity arranged to approximate the distributed resistance and capacity of the cable. Sometimes inductance units are added to balance the small inductance which even a non-loaded cable has. In the actual operation of cables, artificial lines are adjusted with the greatest care and a remarkable precision of balance is obtained. This is necessary because of the great difference in current amplitude of the outgoing and incoming signals, the former being of the order of 10,000 times the latter. It is quite obvious that it will be much more difficult to secure duplex operation with a loaded cable than with one of ordinary type, since not only do the copper resistance and the dielectric capacity have to be balanced, but the artificial line must also be provided with inductance and a-c. resistance. Also the sea-return resistance and inductance which vary with frequency must be balanced.

In view of these difficulties, it will probably be impossible to get as great a proportionate gain from duplex operation of loaded cables as is secured with ordinary cables. However, it is quite evident that it will be possible to obtain duplex operation at some speed, since, with loaded as with non-loaded cables, the ratio of received-to-sent current increases rapidly as the speed is reduced, and on this account it is much easier to duplex the cable at low speeds than at high. To make duplexing worth while on a cable with approximately equal traffic loads in both directions, it is, in general, only necessary to get a one-way duplex speed half as great as the simplex speed. In fact, in some cases the operating advantages of duplex would warrant even a slower duplex speed. On the other hand, there are cables on which the traffic is largely unidirectional through most of the day and which would accordingly require a one-way duplex speed somewhat higher than half the simplex speed to justify duplex

Fig. 6—Test Message

Signals received April 16, 1920 over coil-loaded artificial line equivalent to a 1700 n. m. cable with 30 m. h./n. m. Speed 2240 letters per minute.

operation. Whether a sufficiently great speed of duplexing could be secured to justify designing a cable on the basis of duplex operation could not be judged in advance of the laying of the first cable, and accordingly it was decided to engineer that cable on the basis of simplex operation.

Although it was expected that the new cable might at first have to be operated simplex it should not be supposed that any great difficulty or loss of operating efficiency was anticipated on this account. The speed of the New York-Azores cable is so great that to realize its full commercial advantage practically requires

12. Carson, Trans. A. I. E. E., Vol. 38, p. 345, 1919.

working it on a multi-channel basis; as, for example, with a Baudot code, multiplex system, similar to that used on land lines. Such a system may be conveniently adapted to automatic direction reversal and, with this modification, most of the common objections to simplex operation are removed. Indeed, simplex operation may in this case possess a real advantage over duplex, from the commercial point of view, since it permits dividing the carrying capacity of the cable most efficiently to handle the excess of traffic in one direction.

Although means for making efficient use of the loaded cable have been made available, it should be recognized that the method of operation best suited to satisfy commercial demands must be determined from future experience with cables of the new type. This is especially true with regard to relatively short cables. In this paper the discussion of the loaded cable problem has been confined wholly to the realm of long ocean cables where the limitations of the cable, rather than terminal equipment or operating requirements, determine the best design. This is the simplest case and the one which, at present, seems to show the greatest gain from loading. Where traffic requirements are limited and there is no prospect of ever requiring a speed higher than can be obtained with a non-loaded cable of reasonable weight, the advantage of loading is less and becomes smaller as the weight of non-loaded cable which will accomplish the desired results, decreases. It should not, however, be concluded that loading will not find important application to short cables. Many short cables are parts of great systems and must be worked in conjunction with long cables. In such cases it may pay to load short sections where loading would not otherwise be justified. Permalloy loading also offers great possibilities for multiple-channel carrier-telegraph operation on both long and short cables, and with this type of operation in prospect it is too early, now, to suggest limits to the future applications of permalloy to cables or to predict what will be its ultimate effect on transoceanic communication.

A Vibration Recorder for Pathological Analyses

BY CHESTER I. HALL[1]

Fellow, A. I. E. E.

Synopsis:—*The author describes a new device which has been developed for pathological use in recording the hand tremors of patients, as an aid in the diagnosis of disease. The motion is resolved into its horizontal and vertical components, both of which are given on the record. This instrument is also useful to the engineer for recording mechanical vibrations of various kinds. An important feature is the freedom of the vibrating body from all restrain, due to the optical method employed.*

THE great clinics of the country, organized for the careful, detailed study of the cause, characteristics, prevention and cure of disease, have been calling more frequently of late upon the services of the scientist and engineer. While medicine in general is an art, many of its activities may be converted into terms of one or the other of the exact sciences with a marked gain in the method of obtaining and recording data, the analysis and correlation of facts, and the application of instruments of precision, either already available or requiring development where such instruments can take the place of mere observation, with its attendant inaccuracies and personal bias. All laymen are familiar with the family physician's three "tools" of reliability and proven worth; the watch, thermometer, and stethoscope; but few realize the extent of apparatus in the modern clinic. In addition to the complete chemical and bacteriological laboratories, the equipment includes such devices as the sphygmomanometer, polygraph, basal metabolism recorder, electro-cardiograph, et cetera.

The device to be described forms an excellent example of the possibility of development in indicating or recording instruments to aid the research pathologist or diagnostician in recording data that may be analyzed with much greater accuracy than could be expected without such aid.

In this case the problem presented by the Duemling Clinic[2] was the design of an instrument to record the free arm tremor of a patient, without imposing restraint of any sort and to resolve the motion into its vertical and horizontal components.

FIG. 1—TOP VIEW OF VIBRATION RECORDER

1. General Electric Co., Fort Wayne, Ind.

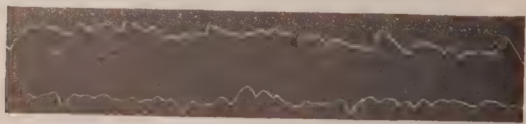
Presented at the Spring Convention of the A. I. E. E. St. Louis, April 13-17, 1925.

2. The recorder described was developed at the request of Charles G. Beall, M. D., Duemling Clinic, Fort Wayne, Ind.

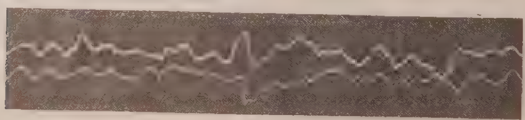
By preliminary study, it was determined that a record at double the amplitude of motion and at a rate of one inch of chart travel per second would make the most desirable curve for the average case. Due to its obvious lack of restraint and inertia the optical method formed the basis of the type of construction finally adopted.

Fig. 2—Taking Muscular Tremor of Patient with a Vibration Recorder

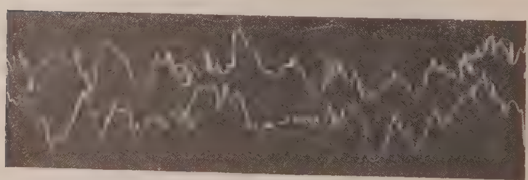
A light source of very minute dimensions was necessary so that a beam much narrower than the amplitude of the smaller vibrations could be used for projection to the recording film. This was obtained by the use of a hemispherical metallic mirror having a radius of curvature of 12.5 mils. Subsequently mirrors of from 10- to 30-mils radius have been produced and successfully used. Such a mirror, when placed end on in a light beam of parallel rays and viewed from any point within its partial sphere of reflection, constitutes a theoretical point source of illumination. Due to inaccuracies of grinding, polishing and lack of uniformity of impinging light its circle of confusion was found to be not over three mils for the 12.5 mil mirror. It will be seen, therefore, that a light source has been obtained which is



a. Myxedema basal metabolism, minus 34 per cent. The secretion of the Thyroid Gland is diminished and many body functions are slowed. Note the low rate, six per sec. (normal rate, 12 per sec.) Compare this with (c), the opposite disease, in which there is an increase of the thyroid secretion and in which many body functions are speeded up.

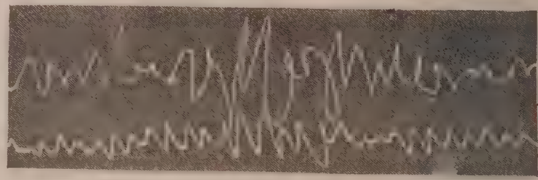


b. Tremor of inveterate tobacco smoker

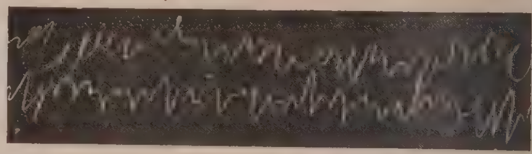


c. Exophthalmic goiter, severe. Note the great amplitude of the vibrations and the loops caused by rapid movement in the direction parallel to the motion of the film. Compare with (a), opposite disease.

Fig. 3—Toxic Tremors (Free Hand Vibrations)

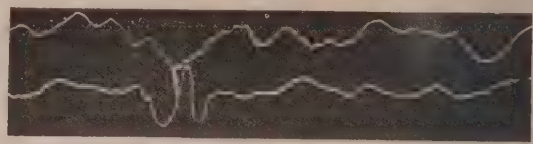


a. Paralysis agitans—Man—Note that the rate is low, amplitude considerable and movement irregular.

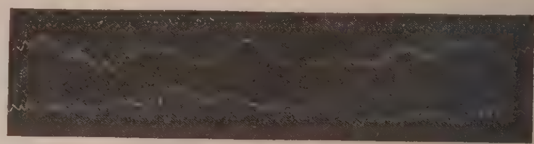


b. Paralysis agitans—Man of 52—The vibrations are of great amplitude but the rate is low.

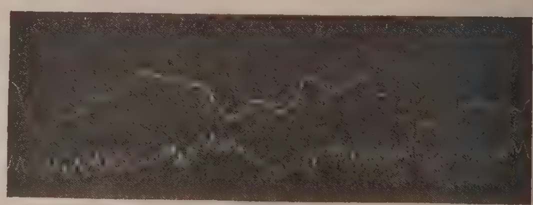
Fig. 4—Organic Tremors (Free Hand Vibrations)



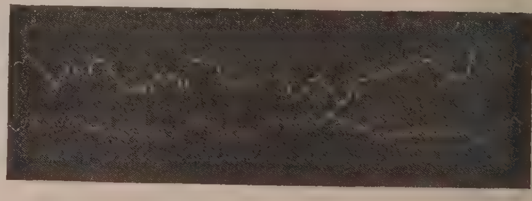
a. Sudden shock caused by dropping glass plate behind patient. This record gives an indication of the time required for recovery from shock.



b. Psychoneurosis—Woman of 32.



c. Psychoneurosis—Woman of 44. The vertical vibrations are of unusually constant amplitude.



d. Psychoneurosis, man of 29.

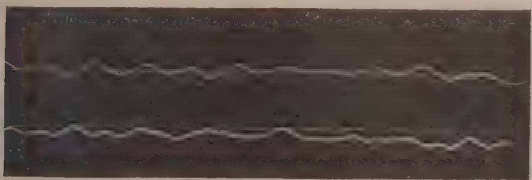
Fig. 5—Functional Tremors (Free Hand Vibrations)

probably smaller than that produced by other methods and with an intensity dependent upon the light flux falling upon it. Further, its inertia is low and the restraint of connecting wires or other attachment, is eliminated.

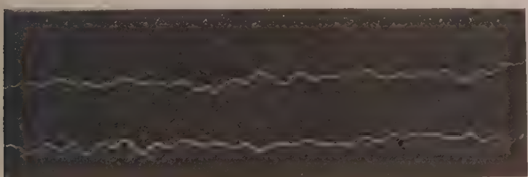
Fig. 1 shows top view of Vibration Recorder. The primary source of light is a standard 6-volt 21-c. p. automobile headlight lamp, located in the rear compartment of the recorder case. The rays from this lamp pass through a condensing lens indicated in the sketch by L_3, and fall upon the miniature hemispherical mirror, A, fastened to a thimble worn by the patient whose tremor is being recorded. This mirror, as previously indicated, furnishes a point source of light of high intensity without imposing restraint upon the vibrating body.

Two beams of light from the hemispherical mirror are utilized, the first in recording horizontal vibration by passing upward to the mirror, M, from which it is reflected and passed through focusing lens, L_1 to the moving film. The second light beam records vertical vibration and passes directly through focusing lens L_2 to the film. The film is fastened to the outside of cylinder, D, which is rotated by a constant-speed electric motor of the induction disk type. The earliest form of this device had to be operated in a dark room, since the film was not protected from outside light.

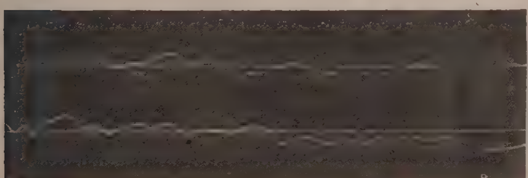
a. Unsupported arm vibration of expert marksman No. 1. This Chart indicates normal pathological vibration and should be compared with the preceding charts which show normal vibration.



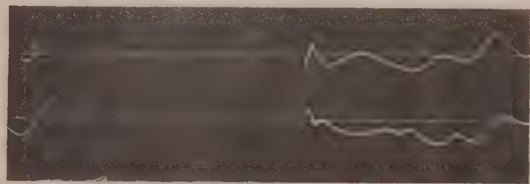
b. Vibration of muzzle of rifle held by marksman No. 1. Note that the frequency is much lower than in (a) on account of the damping effect of the rifle's inertia. The straight line indicates the center of the target.



c. Unsupported arm vibration of expert marksman No. 2.

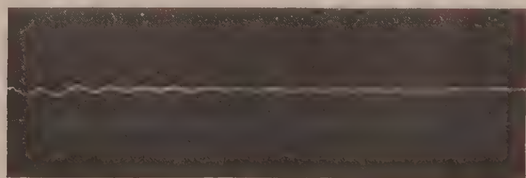


d. Muzzle of rifle held by marksman No. 2.



e. Muzzle of rifle held by poor marksman. Note that record is incomplete, showing that marksman was unable to hold the muzzle within the field of the recorder.

f. Woman of 102 years, normal. Note the small amplitude, indicating extraordinary steadiness.



g. Vibration of an a-c. washing machine motor mounted on sponge rubber supports. The left side of chart shows the starting condition, the motor being shut off at a point somewhat to the left of center of chart—the remainder representing coasting the vibration is caused by rotor unbalance, the waves at the beginning being due to the movement of the stator resulting from the reaction between rotor and stator. Notice that the amplitude of the horizontal vibration was greater after the motor speed had been reduced to a certain value, at which the frequency of the vibration due to unbalance was the same as the natural frequency.

Fig. 6—Miscellaneous Tremors

Daylight Operated Recorder

An improved recorder of the type just described, but one which may be loaded and operated in daylight, is shown in Fig. 2. This cut illustrates the operation of the instrument, showing the operator on the left and patient on the right, the latter holding the tiny mirror in the beam of light. The hood used by the operator shuts out external light and enables him to look through a ruby glass in the cover and see the spots of light which are projected on the film. He is thus able to determine whether or not the patient is holding the tiny mirror within the field of the recorder. The operation of the instrument shown is simple, being somewhat similar to

that of an ordinary camera. It can therefore be operated by any physician without previous experience or special knowledge of this type of instrument.

The daylight operated recorder is an entirely self-contained and independent instrument. The light source is operated from dry cells contained within the cabinet. The film, which is of standard size, is driven by a hand-operated crank. Constant speed of travel for the film is maintained by means of a fly-ball centrifugal governor with a clutch which releases the film driving roller when the speed exceeds a predetermined value. In operation it is therefore simply necessary to turn the hand-crank at any speed greater than a certain minimum value and the operation of the governor and clutch insure constant motion of the film at the given speed for which the governor is adjusted.

The interior of the daylight-operated recorder is shown in Fig. 1. This indicates the general arrangement of parts, showing dry cells, lenses, reflecting prism, et cetera. The automobile lamp, used as the primary source of light, is enclosed in the rear of the compartment shown on the right-hand side of the illustration. This lamp is controlled by contacts operated by a push button mounted in the cover. The film holder and re-roll mechanism are located in the left side of the cabinet as viewed in Fig. 1.

The source of light and optical system used in this recorder are such that the recording points of light on the film are of very small diameter and high intensity. A clear record is therefore produced and the illumination is sufficient so that if desired records may be made on bromide paper.

Application to the Study of Muscular Tremors

Tremors of diagnostic importance occur not only in organic diseases of the nervous system, but also in certain other conditions. Physiology teaches that muscles in health are held in tone by mild impulses delivered into them along the motor nerves at the rate of about twelve a second. No tremor is then perceptible; but if the impulses are of increased or diminished frequency, are exaggerated or irregular in force or rhythm, they become perceptible to the unaided eye or touch.

According to the immediate cause, tremors may be divided into three groups as follows:

I. Toxic Tremors—including those due to tobacco, alcohol, alkaloids, metals, hyperthyroidism, and probably those due to exhaustion.

II. Organic Tremors—embracing tremors due to brain lesions, general paresis, multiple sclerosis, posthemiplegic conditions, paralysis agitans and senility.

III. Functional tremors—including tremors due to fear, hysteria, neurasthenia and various other psychoneuroses (Crenshaw).

An interesting collection of records showing tremors of each of the three classes is shown in Figs. 3a to 5d inclusive.

Other Applications

The application of the recorder described in this paper is by no means limited to the study of muscular tremors, although this use is the one for which it was originally designed. A number of interesting and useful applications have already been suggested and tried, such as recording the vibration of motor frames, transformer coils under heavy overload, and the muzzle of a marksman's rifle.

Records showing the vibration of the rifle muzzle for two expert marksmen are shown in Figs. 6b and 9d. Unsupported arm vibrations of these marksmen are also given. Fig. 6e shows the rifle muzzle vibration for a poor marksman. This record is incomplete due to the fact that the marksman was unable to hold the muzzle within the field of the recorder throughout the time the record was being made.

Fig. 6g shows the vibration of the frame of an electric motor during starting and coasting conditions. This record illustrates the use of the recorder in the study of various kinds of mechanical vibrations.

The examples given in the foregoing are typical of the applications to which the vibration recorder can be put. Other uses will no doubt appear from time to time as the device becomes better known and its possibilities more fully understood.

Explanation of Charts

In each of the foregoing charts, the upper line records horizontal vibrations and the lower line shows vertical vibrations. Ordinates give the magnitude of vibrations, multiplied by two. Chart movement is at the rate of one inch per second and reads from left to right in each case.

RADIO IN WARSAW, N. Y.

Receiving troubles which have for sometime baffled Warsaw and vicinity appear to have been terminated by the result of investigation made by V. W. Spears, electrical engineer for the Interstate Public Service Company at their office in Indianapolis, in localizing the interference which, for the past six months, has made radio reception in that locality practically impossible. Correction was accomplished by the discovery of a high-powered electrical leak. A leaky bushing was found in the transformer at the Warsaw Water works and power house on North Buffalo Street. This has been sending a throbbing noise into the ether and for months puzzling radio experts.

The Transformer is one used in sending power to Claypool and Silver Lake from Goshen and through Warsaw. The leak became a broadcasting station blanketing the whole band of wave-lengths for radio reception and causing a constant hum in the loud speakers. Radio enthusiasts are delighted with the results obtained and C. C. Argabrite, chief of the electrical engineers of the Interstate has received a letter from Warsaw officially expressing their appreciation of the conquering of this difficulty.

Two-Phase, Five-Wire Distribution
Its Engineering and Economic Elements

BY P. H. CHASE[1]
Member, A. I. E. E.

Synopsis:—*In view of the present trend toward three-phase secondary distribution involving, in some cases, a change from a two-phase system, an analysis of the engineering and economic elements of a two-phase system may be of value. The two-phase five-wire secondary system is examined in the light of fundamental requirements, such as service continuity, safety, standard voltages, flexibility, low cost, etc., and compared particularly with the three-phase, four-wire star system. Many of the advantages of the two-phase, five-wire system result from the diametrical connection of the two phases, from the inherent balance thereby obtained, and from the greater power carried per wire. An important advantage of the two-phase, five-wire system lies in the fact that single-phase, two-wire and three-wire loads and two-phase loads can be supplied at standard voltages from combination lighting and power secondaries and that new loads can be flexibly supplied through all stages of load growth. There are marked advantages from a construction and operating point of view in having ordinarily only two transformers in banks which supply two-phase secondaries from either two-phase or three-phase primaries. The two-phase, five-wire system has certain advantages as to metering and a comparison of the first cost and the annual cost of two-phase and three-phase motor installations, with wiring, shows small differences. The inherent cost differential between two- and three-phase secondaries with several types of primary systems is shown to be of such a small magnitude that the cost of change over from one type of system to another may over shadow the theoretical savings. Accordingly, with a relatively small inherent cost differential between the existent system and one having certain, more or less, proved advantages and disadvantages, the central station engineer must produce extremely strong arguments leading out of his local situation in order to justify a change from the existing system.*

* * * * *

Engineering and Economic Elements of Two-Phase, Five-Wire Distribution

SINCE the inception of alternating current distribution, initially single-phase, there have been developed various schemes of polyphase distribution, the oldest of these being two-phase. For more than the past decade the change-over of distribution systems from two-phase to three-phase has been considerable. Usually the justification for the change-over of any distribution system lies in the particular combination of conditions which appertain to the territory and system in question. It may be unsafe to derive conclusions for any particular locality from those reached in another locality or from generalized or purely theoretical grounds.

The subject of the best type of distribution system has received intensive study by many electric companies and, in view of the present general trend to three-phase, it is felt that many of the features of a recent analysis of a system which still has two-phase distribution for its secondary and 2300-volt primary systems, will be of particular interest at this time.

For reasons which will be stated later, this paper gives consideration to secondary distribution suitable for the supply from the same mains of both light and power, with only such references to primary distribution as appear necessary for completeness. Distribution transformers, however, are treated as a part of the secondary system.

Fundamental Requirements

As a basis for further discussion, the fundamental requirements which must be met by any secondary distribution system, in order to meet the requirements of the customer with safety and economy, are outlined.

Customers' and Utilization Requirements

1. *Service Continuity.* A high degree of service continuity is required for all classes of service. This is afforded by various feeder, main and service combinations with their requisite protective equipment to afford the desired service insurance.

2. *Safety.* For a secondary distribution system, the requirement for safety is met according to present accepted ideas by a service voltage of approximately 115 from any wire to ground. Existing wiring standards and appliances allow this voltage to be handled safely for a wide diversity of applications.

3. *Standard Voltage.* The voltage for lamps has been standardized at 115 volts, with 120 volts as an allowable higher figure. The voltage for motors for combined light and power systems has been standardized at 110 and 220. Any system of distribution should conform to these basic voltage standards, established through years of experience and investigation.

4. *Voltage Regulation and Balance.* The inherent voltage regulation and balance of the secondary distribution system must be such that, with the usual voltage regulating equipment at the substation, the variations of service voltage, on all phases, and under all load conditions, will be kept within a value which will not impair illumination from lamps nor service from motors and appliances.

5. *Customers' Equipment and Wiring.* The type of distribution system should be such that the customers' equipment may be of standard, readily secured types and the wiring simple, efficient and inexpensive.

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1. Asst. Engr. Trans. and Distr., Philadelphia Electric Co., Philadelphia, Pa.

Presented at the Annual Convention of the A. I. E. E., Saratoga Springs, June 22-26, 1925.

Distribution System Requirements

1. *Simplicity and Standardization.* Separate or combination light and power service should be readily available from a single set of mains in order to take the maximum advantage of diversity between power and lighting loads. The distribution system should make use of standard equipment.

2. *Load Balance.* The secondary distribution system should be readily adapted for service both to single phase and to polyphase loads without material load unbalance between the phases.

3. *Voltage Balance.* The voltages of the different phases should remain balanced with respect to each other and to ground.

4. *Adaptability to Physical Conditions.* The distribution system should be equally adaptable to aerial or underground construction, to urban, suburban and rural conditions, and to residential, commercial and manufacturing districts.

5. *Growth Adaptability.* The secondary distribution system should be adaptable to all stages of load growth and load density, by means of additions and reinforcement, and with the minimum amount of reconstruction work at any stage. When the initial single-phase lighting load in residential areas eventually develops demands for polyphase service, the distribution system should be sufficiently flexible to render such service without extensive changes.

6. *Investment.* There should be the minimum investment in mains, services, transformers, meters, etc. The annual charges on the investment are usually the largest portion of the total annual cost of the secondary distribution system.

7. *Power Losses.* The secondary distribution system should have low power losses. This requirement is usually met when the requirements for voltage regulation are properly met.

8. *Operating and Maintenance Costs.* These costs should be low. They usually will be a fairly constant percentage of the investment.

Combined Light and Power Secondaries

The treatment of the subject throughout is based on the requirement of a system suitable for the supply of power and lighting, either single-phase or polyphase, from the same mains. A study of the economic advantages of combination mains, under assumed average conditions, points toward savings of the order of twenty per cent in the total annual cost (fixed charges and losses) of transformers, mains and services, as compared with separate transformers, mains and services for lighting and power. It is recognized that there are and will be many instances, particularly on aerial systems, where the use of separate lighting and power mains is necessary to prevent fluctuating power loads or the frequent starting of motors from impairing lighting service, and that on many systems the mileage of separate lighting and power mains greatly outweighs the mileage of combined mains.

The Two-Phase Five-Wire Secondary System

The two-phase, five-wire secondary system is shown schematically in Fig. 1. The system is strictly a four-phase, five-wire *diametrical* system, with 115 volts to neutral. This *diametrical* connection is responsible for many advantages of the two-phase system, owing to the relative independence of the phases. If there is any virtue in the *number* of phases, surely such a four-phase system should compare favorably with the three-phase!

The two-phase, five-wire system has the following outstanding features:—

1. Standard 115 volts for lamps and appliances.
2. Standard 115 or 230 volts for motors.
3. Voltage to ground balanced.
4. Load balanced.
5. Two transformers per bank.
6. Transformers or standard ratio and voltage.

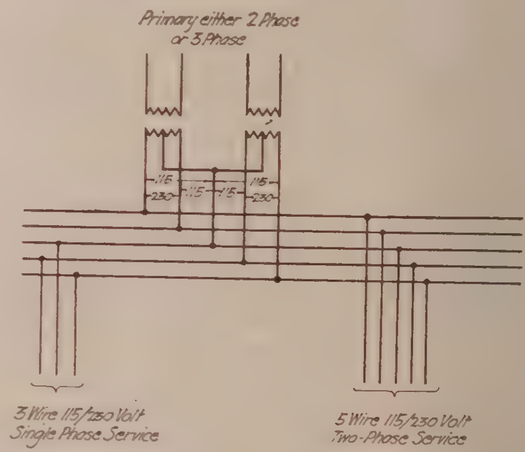


Fig. 1—Schematic Diagram of Connections for Two-Phase Five-Wire Secondary Mains

Power per Wire

Considering the secondary distribution problem from a fundamental point of view, it will be realized that the condition which largely influences the economic advantages of one system over another is the *amount of power carried per wire.* Table I shows the amount of power per wire for various systems, all with 115-volt lamp voltage (E), assuming the same current (I), per

TABLE I
POWER PER WIRE

System	No. of Wires	Power Carried	Power Carried Per Wire
5-wire 2 ϕ 115-230 Volt...	5	4 $E\,I$.	4/5 $E\,I$. = 0.80 $E\,I$.
4-wire 3 ϕ 115-199 Volt...	4	3 $E\,I$.	3/4 $E\,I$. = 0.75 $E\,I$.
3-wire 1 ϕ 115-230 Volt...	3	2 $E\,I$.	2/3 $E\,I$. = 0.667 $E\,I$.
2-wire 1 ϕ 115 Volt.......	2	$E\,I$.	1/2 $E\,I$. = 0.50 $E\,I$.*

*Voltage regulation requirements will often operate to reduce this value as a comparative measure of power per wire.

wire and the same size wire. This comparison is based on equal voltage drop and therefore represents equivalent conditions for the distribution systems set forth.

The two-phase, five-wire system carries 6.6 per cent greater power per wire because, with 20 per cent more copper, it carries 33 ⅓ per cent more power than the three-phase four-wire system having the same lamp voltage.

Inherent Advantages

Consider the inherent advantages of the two-phase, five-wire system. It has a fifth or neutral wire common to two *independent* 115-230-volt phases. A current in the neutral is caused only by a load unbalance on one side of a phase and this is ironed out in the transformers.

The neutral of the three-phase, four-wire star system, and also the transformers, will carry the resultant current due to any line—neutral load unbalance, and thus transfer the unbalance to the primary mains.

In a secondary distribution system, which ordinarily supplied both single-phase and polyphase loads of various types, there is inevitably unbalance between line and neutral loads and the effect of this upon the voltage balance of the system is inherently greater with the three-phase, four-wire star system than with the two-phase five-wire system.

In the aerial plant, standard cross arms and racks can be utilized practically as efficiently by the two-phase, five-wire system as by the three-phase, four-wire system. Four wires utilize practically as much space as five wires and the four wires will have to be larger for the same amount of power carried under the same conditions.

In the underground plant the two-phase five-wire system can make use of single conductor, two-conductor, three-conductor, or four-conductor cable as local duct, heating, loading and service conditions warrant. Under many conditions, where it is economically preferable to install mains on two sides of a street, the two-phase, five-wire system affords a very flexible method of rendering service to loads largely single-phase on each side of such a street while still maintaining balanced load on the mains and phases.

With heavy load densities, the two-phase five-wire system may readily be accommodated with one phase in each of two ducts. There is a consequent improvement in the transmission of heat from the cables and a decrease of the hazard to service from one phase in the event of a fault on the other phase. The three-phase, four-wire star system requires a voltage unbalancing arrangement of the cables if two ducts are used, unless all three phase conductors are in each duct.

Although local conditions will materially affect the handling of any underground system, it is felt that the two-phase, five-wire system has at least every advantage that the three-phase, four-wire has in best utilization of pole and duct space.

Comparison with Three-Phase Four-Wire Star System

On the other hand, the three-phase, four-wire secondary system forces the distribution engineer into a choice of one of the following dilemmas:

1. A decrease in the motor service voltage to 199 volts nominal, with 115-volt lamp voltage. This may require the development of a new line of motors, or the de-rating or under-loading of the present line of 220-volt motors.

2. An increase in the lamp voltage to 133, thus bringing the motor service voltage to 230. This requires the introduction of a new line of lamps and appliances and a new line of distribution transformers, or the marked over-excitation of the present standard ratio transformers to give 133 volts, secondary. Also changes to present standards for substation equipment might be necessary.

3. A compromise raising the lamp voltage to around 125, and decreasing the motor voltage to around 216. This presents complications with lighting, appliance and motor loads, as the compromise voltages are often high for lamps and appliances and materially, if not seriously, below the 230-volt standard for motor service.

4. The use of auto-transformers for stepping up the main voltage of 115-199 to 230 volts for motors. Under conditions where the lighting and power loads on a secondary main system are approximately equal, it would then be necessary to transform one-half of the load from 115-199 volts up to 133-230 volts by means of auto-transformers. Assuming an average connected load per power customer of 12.5 kv-a. in power, a fair average figure for an underground city area, it is estimated that the necessary auto-transformers, (excluding installation costs) would cost more than twenty-five per cent of the entire investment in secondary mains, conduits and manholes.

The service which on the two-phase, five-wire system would be three-wire 115-230 volts single-phase, on the three-phase, four-wire system must be either (a) two-wire 115-volt single-phase, or (b) three-wire 115-199 volt open "Y" or (c) three-phase, four-wire. Each of these solutions results in higher losses, poorer voltage regulation, unbalanced voltage, higher investment, singly or in combination.

The two-phase, five-wire system requires none of these compromises or sacrifices.

In this comparison, consideration has not been given to the various other three-phase secondary systems which do not have some of the disadvantages of the three-phase "Y"—connected system. They have other combinations of disadvantages which are summarized in "Alternating-Current, Low-Voltage Networks," Serial Report of the N. E. L. A., Publication No. 25-1.

Transformer Installations

For the purpose of this paper, the transformer installation for supplying the secondary mains from the

primary distribution system is considered as a part of the secondary system. In considering the transformer installation, it is fully as important that attention be directed to the construction and cost elements of the supporting structure for the transformers if on a pole, or to the manhole or vault if the transformers are subway type.

For the two-phase, five-wire 115-230 volt secondary distribution system, the connections will be as shown in Figs. 2A and 2B for a two-phase primary and in Fig. 2C for a three-phase primary. In all of these combinations, for a given size bank, only two transformers, or a multiple of two, are required. For the three-phase, four-wire system, three transformers, or a multiple of three, are required. The use of polyphase transformer units is practicable for either two or three-phase, but certain service and operating advantages are generally felt to be lost as compared with standard single-phase units.

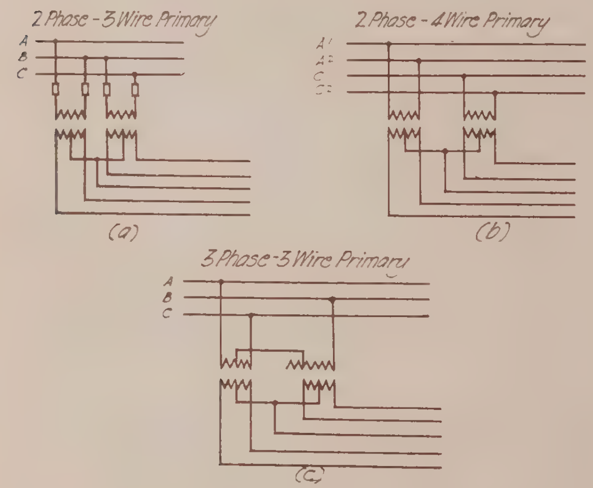


Fig. 2—Transformer Connections for Supplying Two-Phase Five-Wire Secondary Mains from Two-Phase or Three-Phase Primary Circuits

There are marked advantages of having ordinarily two transformers per bank, with the two-phase system. On the aerial system, two units can be hung or arranged much more readily on a pole, with minimum decrease of working and climbing space for linemen. The mechanical advantages of a balanced transformer arrangement are apparent from Fig. 3. In the underground system, the use of two transformers is generally more economical of manhole space than the use of three transformers.

With two-phase primaries, standard transformers may be used in connection with the five-wire two-phase secondary system. In the case of three-phase primaries, standard transformers with Scott taps are readily available at a slight increase in cost per unit.

The Scott connection and the combination of three-phase primaries with two-phase secondaries has sometimes been referred to as a hybrid scheme. Let us reserve judgment on this matter and base our conclusions upon common-sense engineering which must recognize construction, operating and cost facts in addition to purely theoretical considerations.

In the modern Scott-connected transformer bank, there is a voltage unbalance of the order of one and one-half per cent and a phase displacement of the order of one and one-half degree at eighty per cent power factor and much less at higher power factors. It can be readily shown that the per cent voltage unbalance caused

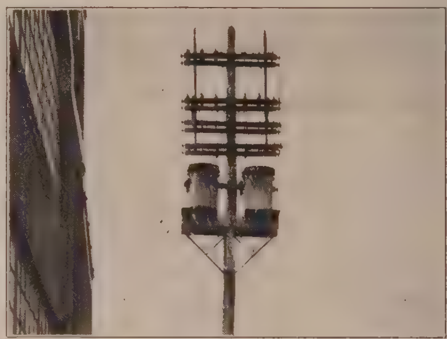


Fig. 3—Typical Construction—Two-Phase Transformer Bank

by 100 amperes per wire in approximately 500 feet of three-phase, 115-199 volt, four-wire No. 00 secondaries on a cross arm with standard 14½-inch spacing is about the same as in a Scott-connected transformer bank having approximately five per cent impedance. There is no such inherent unbalance in two-phase, five-wire secondaries, when properly grouped, as the phases are separate and diametrically connected. The existence of current in the neutral will affect the voltage balance

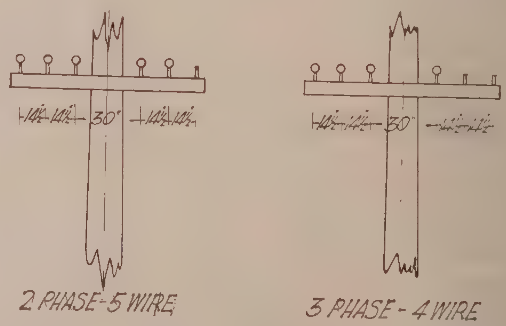


Fig. 4—Typical Arrangements of Secondary Mains on Cross Arms

of the three-phase system more seriously than that of the two-phase system.

See Fig. 4 for typical arrangements of wires on a cross arm.

For an economic statement of the cost differentials between aerial transformer banks of the standard type connected (1) two-phase to two-phase, (2) three-phase to two-phase and (3) three-phase to three-phase, refer to Table II, which shows the comparative invest-

TABLE II
COMPARATIVE COST OF AERIAL TRANSFORMER INSTALLATIONS

Distribution System	Two-Phase—Two-Phase 2300-115/230 Volt	Three-Phase—Two-Phase 2300/3984-115/230 Volt	Three-Phase—Three-Phase 2300/3984-115/199 Volt
Number of Transformers per Bank	2	2	3
Voltage Rating of Transformers	2300–115/230	2300/4600–115/230.*	2300–115/230
150-Kv-a. transformer bank			
Total Investment	$1,096.00	$1,249.00	$1,353.00
Investment per kv-a	7.31	8.33	9.02
Total annual cost per kv-a.†	1.30	1.46	1.54
75-Kv-a. transformer bank			
Total Investment	678.00	783.00	774.00
Investment per kv-a	9.04	10.43	10.32
Total annual cost per kv-a.†	1.55	1.81	1.77
15-Kv-a. transformer bank			
Total Investment	286.00	339.00	337.00
Investment per kv-a	19.07	22.60	22.47
Total annual cost per kv-a.†	3.10	3.74	3.62

*Transformers are the type rated at 2300/4600–115/230 volts with taps for 3984 and 3444 volts and will give full rated output when Scott-connected.
†Total annual cost includes fixed charges on investment and cost of losses evaluated on increment cost basis.

ments and annual cost (fixed charges and cost of losses) estimated on a comparative basis.

It will be noted that the costs for the two-phase to two-phase banks are distinctly less than for the other connections, and that the three-phase to two-phase and the three-phase to three-phase costs run very close.

The three-phase to two-phase transformer costs are based on a relatively costly unit with taps suitable for either a 4000-or 4600-volt primary, while the three-phase to three-phase transformer costs are based on the standard 2300 volt unit. The three-phase to two-phase scheme therefore would allow a primary voltage of 4600 with consequent appreciable primary feeder savings as compared with 4000 volts.

It is therefore apparent that the two-phase, five-wire secondary system may be readily supplied economically from either two-phase or three-phase primaries.

Growth Adaptability

The two-phase, five-wire system, a combination of two single-phase, three-wire systems, possesses a high degree of flexibility and adaptability to all stages of load growth in a distribution system. Generally a district initially is supplied from single-phase three-wire, 115-230 volt mains. As the district develops demands for polyphase supply to motors, this stage of development is readily met, especially with a two-phase primary system, by extensions of existing adjacent three-wire single-phase secondaries supplied from different primary phases, thus affording a five-wire, two-phase service with the minimum additional investment in transformer installations and secondary mains, as diagrammatically shown in Fig. 5. If the primaries are three-phase, and as the amount of motor load grows, the transformers will be erected in banks of two, and part of the secondary mains will become five-wire. A three-wire service from mains originally three-wire, when the mains are increased to five-wire, requires no change in the motor or to the customer's wiring. There is, accordingly a large degree of growth, flexibility with the two-phase system. This is also a result of the inherent high capacity per wire, of particular value with continuing growth of load where theoretical considerations often are completely outweighed by the necessity of providing reasonably for development.

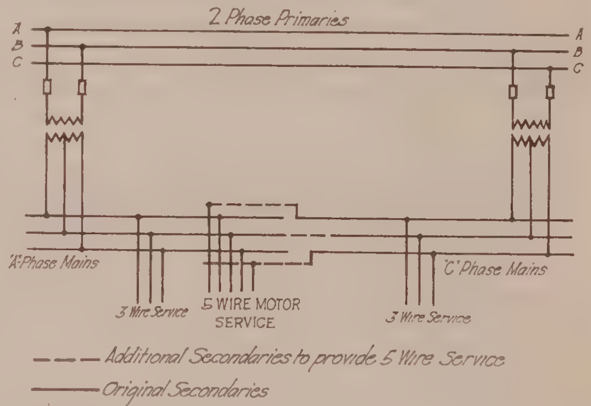


Fig. 5—Typical Method of Development for Two-Phase Five-Wire System

With the three-phase, four-wire system, it is apparent that if a district is permitted to originally develop on a single-phase, three-wire basis, when it becomes necessary to provide for polyphase loads, the erection of two additional transformers will be necessary and also the conversion of the three-wire, single-phase secondary mains to four-wire, three-phase, unless such expedients as open "Y" three-wire mains are resorted to.

In such a transition it will be necessary to care for every three-wire, 115/230-volt, single-phase customers' service in one of the following ways:

1. Change to four-wire, three-phase. This requires running an additional wire, replacement of the single-phase meter by a polyphase meter, and changing the customers' wiring for a four-wire service.

2. Change to two-wire, 115-volt, single-phase. This may require larger service wires, and a change to a two-wire meter. In many situations, as with electric range loads, such a change would greatly increase the voltage

drop or necessitate a separate service to maintain the proper voltage on lamps.

3. Change to three-wire, three-phase 115/199-volt open-"Y." This will require a second meter or replacement of three-wire meters by polyphase metering. The service voltage will be unbalanced by the current in the neutral and the losses will be much higher in the service wires and the main neutral.

If the mains are made four-wire initially, there is the initial extra investment in transformers and mains, and the unavoidable choice must be made between the above three types of services, each with its disadvantages as compared with the three-wire, 115/230-volt service. The importance of this situation is apparent from the relatively large proportion of services which are single-phase on most systems.

Although many situations of the above nature are being solved by the use of separate mains for light and power, the substantial savings in combined mains it is felt compel consideration of any secondary system from the point of view of its suitability to the ultimate supply of practically all types of small and medium size loads from the same mains. To this end stricter requirements in motor starting currents and improved methods of distribution should be considered.

Relation of Primary Distribution

Although this paper deals particularly with secondary distribution, there are a number of related points in connection with primary distribution which should be borne in mind.

Primary distribution is affected by a large number of variable elements, including:

1. The size and spacing of substations.
2. Length and capacity of feeders.
3. Density and character of load, both primary and secondary.
4. Type of system, radial, parallel, loop, network feed, aerial, underground, etc.
5. Configuration of streets.
6. Tree conditions.
7. Governmental restrictions relating to voltage, aerial construction, tree trimming, etc.
8. Contractual restrictions such as those relating to voltage, type of construction, etc., in joint pole use.

Again, as in the case of secondary distribution, the influence of local conditions upon the type of system is very great and it is often difficult to make comparisons between systems in different localities.

It is desired in connection with primary distribution to call attention to one factor which in recent years has become of increasing importance in this involved problem. Pressure of increasing-load demands by the public and the desire for greater economies by central station engineers in the use of copper and the saving of losses, have of late greatly accelerated the increase from 2300 to 4000 volts, to 6600 and 11,000 volts, and to 13,200 and 22,000 volts. The economies have resulted, not particularly from any change in the number of phases as such, but from *the higher voltage.* This voltage increase has progressed in a way undreamed of twenty, or even ten, years ago.

Improvements in insulators, protective devices and all materials used in the distribution plant have resulted in gratifying operating experience and have practically wiped out the older, natural distrust of voltages higher than 4000 volts. The great economic savings of these high voltages therefore have been taken advantage of in recent years by many companies.

The situation in some instances is that of a superposition of a primary distribution system with voltages such as 11,000 and 13,200, over the present 2300-or 4000-volt primaries. There is either direct transformation to the secondary mains or utilization of the present 2300- or 4000-volt primaries, merely as an intermediate short-haul facility.

Thus, this tendency in primary distribution, where prompted by local conditions, appears to be toward what may be called super-distribution circuits, often at generated voltage, with consequent lower substation costs from the omission of transformers and with lower losses, instead of toward a moderate change of voltage such as from 2300 to 4000 volts.

The strength of this idea lies in the probability that a moderate increase in the primary voltage, so often resulting in marked theoretical economies in primary copper investment and losses, may require expensive reconstruction of substations, distribution plant and, often more serious, costly change over of primary customers' installations. The additional investment, power losses, operating and maintenance costs of the duplicate plant during a long transition period require very careful consideration in order to avoid a long postponement of actual net savings from the change. Further, during the change over, the load conditions may have so changed that the primary system has become inadequate to meet the new conditions and another increase in voltage may be required. A glance backward over the history of power distribution should constitute a warning as to the possible futility of taking too early what may later stand out as only a make-shift economic step. These statements apply with equal force to secondary distribution.

Metering, Motors and Customers' Installations

In the two-phase five-wire system, single-phase service loops generally are two-wire for loads up to a prescribed figure and three-wire for loads in excess. For the former range of loads, which are representative of small residential consumers, the metering is identical whether from a two-phase or a three-phase system. For the latter range of loads the metering costs involve a comparison between a three-wire, single-phase meter for the two-phase system and polyphase metering or raising the limit for two-wire services for the three-phase system. The cost of a three-wire, single-phase

meter installation is slightly lower than the cost of a two-wire, single-phase meter installation of the same kilovolt-ampere capacity and is very much less than any type of polyphase metering now in use.

For metering polyphase power load, there is practically no difference in the meter costs for two-phase or three-phase.

A study of metering costs for a typical system including all types of metering, indicates that the total investment in metering equipment would be about fifteen per cent greater for the three-phase system than for the two-phase system.

The cost of two-phase motors of the usual voltage and speed ratings is identical with that of three-phase motors. In some cases there is a slight additional cost for the starting compensators for two-phase motors. The two-phase motor at rated full load has an efficiency slightly less than the three-phase motor, for the usual voltage and speed ratings, which is of the order of one per cent for sizes up to about 25 h. p. and less for larger sizes. This difference is due partly to the slightly less efficient coil design for two-phase and partly to the fact that most manufacturers design parts which are interchangeable for two-phase and three-phase motors but which are not always quite the most efficient design for two-phase motors. The torque characteristics of the two-phase motor are as good as if not better than the three-phase motor, according to manufacturer's rating sheets. The effect of reduced voltage under some of the three-phase four-wire schemes is to materially decrease the pull-out torque of the standard 220-volt motor.

The two-phase, five-wire system uses standard motors of standard 220 volt rating while the three-phase, four-wire system with 115/199-volt mains require the development of a new line of 199-volt motors or the material de-rating of the present line of motors,(unless auto-transformers are resorted to), thus resulting in a distinctly unfavorable situation.

It has been claimed that the two-phase, five-wire system, which for motor service requires four-wires as against three wires for the three-phase system, requires more expensive wiring. Comparative estimates prepared for motor sizes from 10 to 50 h. p., both three-phase three-wire and two-phase four-wire show differences of the order of one per cent, in some cases in favor of the two-phase and in some cases in favor of the three-phase.

These figures are based on 220-volt motors for both two-phase and three-phase. If the cost of the necessary auto-transformers were included with the three-phase motor or allowance made for the additional cost of a 199-volt motor with its wiring, to be supplied from 115/199-volt mains, the comparison would be favorable to the two-phase system.

A typical example will serve to illustrate the small magnitude of the difference of the losses in a two-phase motor with its wiring, and a three-phase motor with its wiring. Assuming a 10-h. p. motor first three-phase, 199-volt, and second, two-phase 220-volt; the difference in the value of losses for a period of operation of 2000 hours per year at an average of 75 per cent full load, at two cents per kw-hr., amounts to less than $2.75 per year in favor of the three-phase motor. This is less than one per cent of the value of the power input to the motor and is of such a small order of magnitude as compared with the usual variables of installation costs, over-sized motors, operating hours, length of wiring, etc., that it should not be considered of importance in the choice between a three-phase and a two-phase system.

Thus, if the three-phase motor is supplied through an auto-transformer from 115/199-volt mains or the motor is a 199-volt, the carrying charges on the extra investment in motor and wiring, or in auto transformers, and the additional losses would throw the saving in favor of two-phase.

With a three-phase motor service voltage of 199 volts, the voltage drop in the wiring in many cases will result in a materially lower voltage at the motor terminals. Using the same per cent in this case as is nominally allowed between a 230-volt service and a 220-volt motor, the rated motor voltage should be 191 volts.

For lighting loads there are difficulties with the three-phase, four-wire system which do not exist with the two-phase, five-wire system. The main feeds to panel boards must be either four-wire 115/199-volt, with a more expensive four-wire panel board, or they must be three-wire open "Y" with the losses in the wiring approximately 50 per cent higher than with three-wire, single-phase feeds. There will also be a voltage unbalance due to the assymetrical phase relations of the current in the wires, its magnitude depending upon the power factor, and an increased voltage drop. Single phase three-wire feeds from a two-phase, five-wire system do not have these disadvantages.

General Economic Features of Two-Phase Five-Wire Distribution

It has been seen from the foregoing discussion that the character of service from the two-phase, five-wire secondary system, so far as it meets the various distribution, engineering and customers' requirements, has no serious disadvantages as compared with the three-phase system, and in many respects has outstanding advantages.

Therefore, under such conditions, it will be of interest to compare the overall economies of the two systems, in order to determine the probable magnitude of the cost differential and the importance of this factor as compared with costs of change-over and other factors not readily measured in dollars.

For this measurement of their relative inherent economic standing, an analysis of several combinations of underground primary and secondary distribution systems with two- and three-phase secondaries, was made

TABLE III
TOTAL ANNUAL COST OF NETWORK SYSTEMS
Excluding Operation and Maintenance

No.	Primary	Secondary	Substation	Feeders	Transformers	Mains	Total
			Range of Primary Voltages: 2300–4600 Volts				
1	2-ph. 3-wire 2300/3252-volt	4-ph. 5-wire 115/230-volt	$216,050	$92,900	$118,200	$108,760	$535,910
2	3-ph. 4-wire 2300/3984-volt	3-ph. 4-wire 133/230-volt	211,700	67,120	122,800	97,680	499,300
3	3-ph. 4-wire 2300/3984-volt	3-ph. 4-wire 115/199-volt	211,700	67,120	122,800	101,820	503,440
4	3-ph. 3-wire 300/3984-volt	4-ph. 5-wire 115/230-volt	211,700	67,120	125,300	108,760	512,880
5	4-ph. 5-wire 2300/4600-volt	4-ph. 5-wire 115/230-volt	218,900	93,580	119,600	108,760	540,840
			13,200-Volt Primary				
1	3-ph. 3-wire 13,200-volt	3-ph. 4-wire 133/230-volt	122,900	44,100	147,900	97,680	412,580
2	3-ph. 3-wire 13,200-volt	3-ph. 4-wire 115/199-volt	122,900	44,100	147,900	101,820	416,720
3	3-ph. 3-wire 13,200-volt	4-ph. 5-wire 115/230-volt	122,900	44,100	153,800	108,760	429,560

on a comparative basis, as applied to a definite load and area. Each type of system was given the full benefit of its most economical design. Tables III and IV summarize the results of this investigation. Table III shows the total annual cost of an underground network plant, including in the total annual cost the fixed charges on the investment and the value of the energy losses in the various parts. Table IV shows the investment in the various parts of the plant for the systems considered.

The cost of the mains for the different types of secondary systems does not vary widely, being of the order of magnitude of 10 per cent for the total annual main cost and for the investment in mains. For the transformers and mains together, the cost variation is even smaller in either the 2300-to 4600-volt primary range or with 13,200-volt primary. It will also be noted that the investment in mains is only about 20 per cent of the total plant investment in substations, feeders, transformers and secondary mains. The tables also indicate that the part of the problem demanding further engineering attention is that pertaining to the primary, where higher voltages than 4600 show marked possible economies.

These analyses, although on a comparable basis, cannot evaluate in dollars many of the advantages of the

TABLE IV
INVESTMENT FOR NETWORK SYSTEMS

No.	Primary	Secondary	Substation	Feeders	Transformers	Mains	Total
			Range of Primary Voltages: 2300–4600 Volts				
1	2-ph. 3-wire 2300/3252-volt	4-ph. 5-wire 115/230-volt	$1,695,000	$792,000	$773,000	$938,300	$4,198,300
2	3-ph. 4-wire 2300/3984-volt	3-ph. 4-wire 133/230-volt	1,665,900	584,000	790,000	851,700	3,891,600
3	3-ph. 4-wire 2300/3984-volt	3-ph. 4-wire 115/199-volt	1,665,900	584,000	790,000	880,700	3,920,600
4	3-ph. 3-wire 2300/3984-volt	4-ph. 5-wire 115/230-volt	1,665,900	584,000	830,000	938,300	4,018,200
5	4-ph. 5-wire 2300/4600-volt	4-ph. 5-wire 115/230-volt	1,728,600	816,000	783,000	938,300	4,265,900
			13,200-Volt Primary				
1	3-ph. 3-wire 13,200-volt	3-ph. 4-wire 133/230-volt	1,023,000	402,000	954,200	851,700	3,230,900
2	3-ph. 3-wire 13,200-volt	3-ph. 4-wire 115/199-volt	1,023,000	402,000	954,200	880,700	3,259,900
3	3-ph. 3-wire 13,200-volt	4-ph. 5-wire 115/230-volt	1,023,000	402,000	1,019,000	938,300	3,382,300

two-phase, five-wire secondary system, which it is felt fairly match or outweigh the advantages of the three-phase, four-wire system for a densely loaded underground district.

Other figures which have been prepared lead to the same conclusions for the aerial system.

In the change-over of a d-c. network system to alternating current, it may be possible in the choice of the best a-c. system to consider the particular district as a separate problem, because the d-c. equipment will require replacement in any event. However, existing a-c. areas, both aerial and underground, which eventually will form part of the network area, and the need for standardization on one universal type of system will have a necessarily large, if not a predominating, influence on the decision.

Conclusion

With an existing a-c. system of any type, now rendering adequate service satisfactory to the consumers, and economical and adaptable to growth, the cost of change-over to any other system becomes a very important factor. In addition to those costs of a fairly determinable nature, there are others less susceptible of accurate prediction, such as the extra cost of operating two types of systems during the change over and the effect of a longer or shorter change-over period.

Accordingly, with a relatively small inherent cost differential between the existing system and one having certain more or less proved advantages and some known disadvantages, the central station engineer must have extremely strong arguments leading out of his local situation in order to justfy a change from the existing system.

In conclusion, I desire to express my appreciation of the assistance and suggestions rendered by a number of my associates.

WIRING PRACTISES AND MATERIALS, SWEDEN

Sweden is far advanced in the use of electricity for domestic and industrial purposes as well as in the manufacture of electrical machinery and supplies of various kinds. Throughout the country, power generated by numerous hydroelectric plants is in general use, and to meet the resulting large requirements for equipment an important domestic electrical industry has been developed.

Domestic manufactures consist principally of motors, generators, and large machinery rather than of wiring devices and accessories. German influence prevails in the entire Swedish electrical industry, but many electrical engineers employed by the Swedish manufacturers have studied in the United States and are familiar with American wiring devices and practises.

In Sweden electrical devices and wiring materials are not inspected by any private organization similar in its functions to the American Underwriters' Laboratories. However, there has been some demand for this service, and a movement is now on foot to form the necessary organization.

At present, the Swedish Government issues regulations relative to wiring materials and prescribes rules for installation work.

Insurance companies maintain no regular inspection service, but for their own protection make a practise of examining wiring in factories, stores, and other places, or requiring proof that the installations meet requirements. Subsequently, the insurance companies inspect factory wiring at irregular intervals, sometimes only every three years.

In nearly all cases electric service in Sweden is controlled by the municipalities or the National Government, and private ownership of utilities familiar in the United States is practically unknown. This situation facilitates inspection and uniformity of practise, but at the same time tends to make it very difficult to change or modify wiring rules and practises.

In wiring dwellings of the better class, tubing and, to a lesser extent, rigid iron conduit are generally used, these being concealed in the walls and the ceiling under the plaster. In some buildings, especially in garages, rigid iron conduit is sometimes placed on the surface.

Wiring on porcelain knobs on the surface of walls and ceilings is sometimes used, principally in cellars and damp localities, but wiring in cleats is not common. The use of flexible, twisted pair on small porcelain button insulators is still practised, but it is probable that this mode of wiring will be prohibited in the future, while wiring on knobs and through tubes concealed in the walls will be unknown. Armored cable is used only for special purposes. Lead-covered wire is permissible in stables and in localities exposed to dampness or corrosion, but must be covered with iron armor. Wooden casing or molding is prohibited.

The metric copper-wire gage is standard in Sweden, and the minimum wire permitted for use in wiring dwellings must have a cross-sectional area of 1 sq. m. m. For fixtures and other devices, wire having a cross-sectional area of 0.5 sq. mm. may be installed. The usual rubber-covered wire is required in all cases.

Rotary switches and push-button switches are most commonly used. The tumbler type is also employed, but to a lesser extent. Edison screw sockets are always used, bayonet sockets being almost unknown. Special receptacles or connections near the floor, consisting usually of a porcelain two-pin fitting placed on the surface with a glass ring attached to the wall in back of it, are provided in most houses.

In order to prevent the consumer using more current than he is paying for a special current control is installed, which after blinking a short time finally shuts off the current when the agreed limit is exceeded.

The wiring rules do not require that any special form of conductor be used for wiring old dwellings in Sweden.—(*Trade Commissioner T. O. Klath, Stockholm*)

Resolution of Transformer Reactance

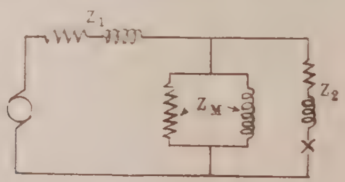
Into Primary and Secondary Reactances

A. BOYAJIAN[1]

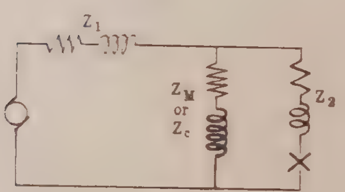
Synopsis.—*The stand is taken that the resolution of the leakage reactance of a pair of windings into the individual reactances of the* [illegible] *referred to a third winding and* [illegible] *object in view when making the* [illegible] *the influence of exciting current on* [illegible] *is converted into a three-winding trans-* [illegible] *ing of the exciting current as produced by a (fictitious) load in a (fictitious) third winding. It is* [illegible] *on of leakage reactance into individual* [illegible] *in the case of three windings, and that therefore in a transformer with three real windings and a fictitious exciting-current-load winding, constituting the equivalent of a four-winding transformer, the simple resolution fails, each winding having a different individual leakage reactance when associated with one pair of the remaining windings than when associated with another pair. Furthermore, the resolution made from the standpoint of real load currents will be different from that made from the standpoint of exciting current. Formulas are given for such resolutions, and experimental methods are described. The problem is also considered from the standpoint of flux distribution and linkages, and the limitations of some common views are pointed out.*

INTRODUCTION

THE old puzzle of the division of the leakage reactance of a transformer into primary and secondary reactances is usually discussed with the tacit assumption that such a division exists in nature,—definite, inherent and absolute,—and that our problem is merely to ascertain its value. But the resolution of the leakage reactance of two windings into the reactances of the individual windings is no more determinate than the resolution of



A



B

FIG. 1

the distance between two points, *A* and *B*, into two parts, one as *A*'s distance, and the other as *B*'s distance. For this reason, it is frequently reported by investigators that the experimental separation of the primary and secondary reactances has failed.

However, if the resolution is desired, not for pure philosophic interest but for a definite concrete object in view, then, this object furnishes us the point of view relative to which the resolution is to be made, and the problem becomes determinate. In every instance where an investigator reports that he has found a means of experimentally segregating the primary and secondary reactances, it will be found that he has referred the resolution to some arbitrary point of reference, probably very useful and valid for his purpose, but arbitrary just the same.

The resolution of leakage reactance into primary and secondary reactances is sometimes necessary for certain practical purposes, as shall be illustrated below, but it will be found in every instance that the resolution which is valid for one purpose is not valid for other purposes, and that, therefore, any such resolution has to be relative and conditional.

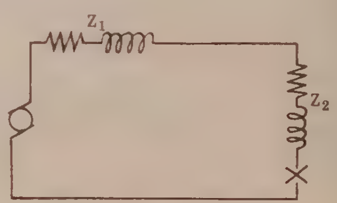


FIG. 2

THE EQUIVALENT CIRCUIT

The classical treatment of a transformer is by means of its equivalent circuit (Fig. 1A or 1B). If the exciting current be ignored, the equivalent circuit becomes like that shown in Fig. 2. If the exciting current is ignored, and the transformer be assumed to have both a secondary and a tertiary winding then the equivalent network becomes like that shown in Fig. 3. Comparing the equivalent network of a two-winding transformer, which draws an exciting current, (Fig. 1A or 1B, especially the latter), with the equivalent network of a three-winding transformer which draws no exciting current, (Fig. 3), the essential identity of the two becomes evident. That is, the standard equivalent circuit of a transformer (Fig. 1) treats the exciting current as though it were a (fictitious) load-current drawn from a (fictitious) third winding. From this standpoint, the

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resolution of leakage reactance into separate primary and secondary reactances becomes a three-winding transformer problem, the general solution of which has been accomplished within the last few years[2] and which we may briefly review here.

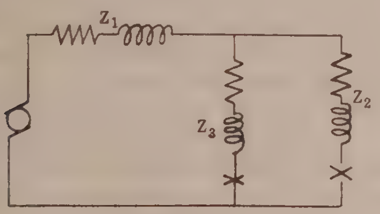

Fig. 3

General Theory of Three-Winding Transformer

In considering the effect of the impedance of a three-winding transformer on its performance, such as regulation, short-circuit current, division of load, etc., we may resolve the leakage impedances between pairs of windings into impedances of the individual windings, the only condition to be satisfied being, that, symbolically,

$$Z_1 + Z_2 = Z_{12} \quad (1)$$

$$Z_2 + Z_3 = Z_{23} \quad (2)$$

$$Z_1 + Z_3 = Z_{13} \quad (3)$$

It may be evident from these equations that the resolution of Z_{12} into Z_1 and Z_2 is made dependent on winding No. 3 by involving Z_{13} and Z_{23}, so that if winding No. 3 is altered the resolution of the leakage reactance between windings No. 1 and No. 2 into Z_1 and Z_2 is also altered. Certainly, any such resolution that is made variable with changes in a third winding cannot be considered absolute or inherent but must be considered purely relative. Generalizing, we may say that a winding may be said to have a definite individual leakage reactance only with reference to two other windings. Referred to less than two other windings, the individual leakage reactance of a winding is indeterminate, any resolution being as good as any other, and all of them being equally needless. Referred to more than two other windings, the reactance characteristics of a winding cannot be completely specified by a single value.

Application to Two-Winding Transformers

In a two-winding transformer the resolution of the leakage reactance into primary and secondary reactances having a significance only in relation to the exciting current, and the exciting current being conceivable as occasioned by a load in a fictitious third winding, the desired resolution, in the light of the theory of three-winding transformers, may be defined as follows. Let C represent the fictitious third winding which simulates the characteristics resulting from the core. The leakage reactances between this fictitious winding C and the real windings No. 1 and No. 2, respectively, may be designated as X_{1c} and X_{2c}. The individual leakage reactances X_1 and X_2, resolved with respect to the exciting current, will be given by

$$X_1 = (X_{1c} + X_{12} - X_{2c})/2 \quad (7)$$

$$X_2 = (X_{2c} + X_{12} - X_{1c})/2 \quad (8)$$

$$X_c = (X_{1c} + X_{2c} - X_{12})/2 \quad (9)$$

The equivalent network of this resolution, as that of a three-winding transformer, is shown in Fig. 4, which is another form of Fig. 1B.

It may be noted that the core exercises a controlling influence on the resolution when made with reference to exciting current, (even though its effect on the total leakage reactance is ordinarily small), but it exercises no direct influence on the resolution when made with reference to load currents as in a three-winding transformer.

If it is desired to consider the element of exciting current in a three-winding transformer, the problem becomes one of four-windings, the exciting current being represented as a load in a fourth (fictitious) winding, as outlined above. In this case no definite, consistent reactance values can be assigned to the windings to indicate their performance rigorously from the standpoint of exciting-current. Furthermore, even

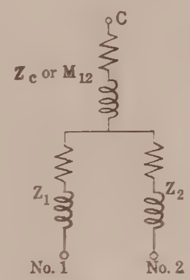

Fig. 4

if this could be done, the reactance values so assigned would be inconsistent with the values required to represent their load characteristics properly.

Individual Leakage Reactances in Terms of Self and Mutual Reactances

Considering the equivalent network of a two winding transformer with its fictitious third circuit, C, (Figs. 1B and 4), it will be evident that the impedance, Z_c, is in series with and common to both of the circuits No. 1 and No. 2, and may, therefore, be recognized as the mutual reactance M_{12} between the two circuits. Z_{1c} will be recognized as the open-circuit self inductive reactance of circuit No. 1, which we may designate as

2. Transformers for Interconnecting High Voltage Transmission Systems by J. F. Peters and M. E. Skinner. Journal A. I. E. E., June 1921, Vol. XL, page 483.

Theory of Three-Circuit Transformers, A. Boyajian, Journal A. I. E. E., 1924, Vol. XLIII, page 345.

Z_1', Z_{2c} as that of No. 2, which we may designate as Z_2'. Evidently,

$$Z_1 = Z_{1c} - Z_c \qquad (10a)$$

$$= Z_1' - M_{12} \qquad (10b)$$

$$Z_2 = Z_{2c} - Z_c \qquad (11a)$$

$$= Z_2' - M_{12} \qquad (11b)$$

$$Z_{12} = Z_1 + Z_2 \qquad (12a)$$

$$= Z_1' + Z_2' - 2\,M_{12} \qquad (12b)$$

Equation (**12b**) will be recognized as classcial. Equations (**10b**) and (**11b**) have been used in the past[3] to define the individual reactances Z_1 and Z_2, but no recognition has been made of their relativity with respect to the exciting current so far as the present writer is aware. These equations (**10b**) and (**11b**) if derived directly, based on the reasoning that the total

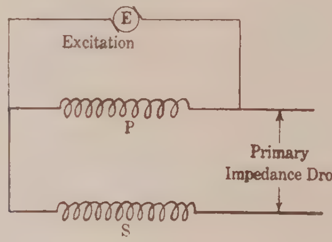

Fig. 5

voltage induced in the winding is the difference between the self-inductive voltage drop and the mutual voltage induced from the other winding, have the appearance of finality. However, when they are derived, as a special case of a three-winding transformer, even though the derivation is roundabout, it is believed that the relativity of the resolution is thereby made clear. So far as utility for practical computation is concerned, neither the set of equations (**7**), (**8**) and (**9**) nor the set (**10b**), (**11b**) and (**12b**) is of a great deal of value.

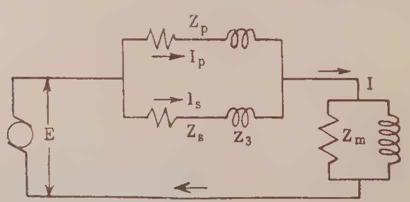

Fig. 6

Their primary use is to define the quantities to which they refer and thus suggest and guide practical methods of calculation.

Experimental Resolution

Consideration of the equivalent circuit of a two-winding transformer, (Figs. 1 and 4), suggests a variety of test methods for the determination of X_1 and X_2. They are very simple and convenient for transformers with 1:1 ratio. Those with other ratios will require either current or potential transformers of the same ratio as their own and the results will naturally be complicated on account of errors of ratio and phase angle introduced by these auxiliary transformers.

1. Regulation due to Exciting Current. The primary impedance drop, due to exciting current, can be measured directly and very exactly in a 1:1 ratio transformer by using the connection shown in Fig. 5. Knowing the current and the impedance drop, the value of the impedance follows by Ohm's law. If the transformer ratio is not unity, a potential transformer of the same ratio would be necessary for the test.

2. Division of Exciting Current. If the two windings, (1:1 ratio) are excited in parallel, they must divide the exciting current inversely as their respective leakage impedances. The equivalent circuit diagram of this

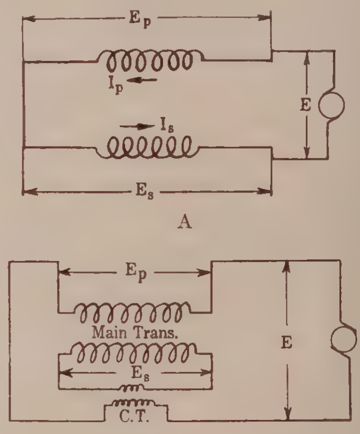

Fig. 7

test condition is shown in Fig. 6. When the ratio is not unity, the windings may be paralleled through a suitable current transformer.

3. Series Impedance Test. With the two windings connected in series opposition, (Fig. 7A), the voltage-drop across each winding can be measured directly, and knowing the current, the individual leakage impedances follow by Ohm's law. With ratios other than unity, the two windings may be connected in series through a suitable current transformer, (Fig. 7B) although the results are likely to be disturbed by the errors of ratio and phase angle of the current transformer.

4. Parallel Impedance Test. If the two windings are excited in parallel-opposition, (Fig. 8), so that the core cannot be magnetized as a whole, the impressed voltage must be balanced by the leakage impedance of the two windings, and the division of current between them will be inversely as their respective leakage impedances.

Absolutely consistent results need not be expected from all these tests. In fact, the results will vary somewhat with varying values of current and voltage even

3. See for instance Rogowski, Dispersion in Transformers, *ETZ*, Vol. XXXI, pp. 1033-1036, 1069-1071; also, Mitteilungen uber Forschungsarbeiten, Heft. No. 71.

when using the same connection. The reason for this is that changes in the permeability of the core at various densities affect differently the reluctances of the external and internal parts of the magnetic circuit, neither the iron magnetic circuit nor the air magnetic circuit, (which are in parallel), having uniform section or length. This fact was forced to the attention of the writer in 1921 while investigating the division of third harmonic current between transmission lines and internal deltas. The method of test and some of the results bearing on the present discussion were as follows:

5. Third Harmonic Tests. The division of exciting current, described under test method No. 2, would, of course, apply to the higher harmonics of the exciting

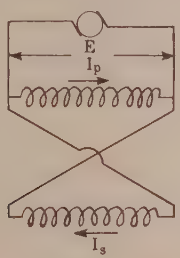

FIG. 8

current as well as to its fundamental, at least to a first approximation. Hence, if two parallel paths are offered to the flow of the third harmonic exciting current, as for instance by two delta-connected windings, (Fig. 9), the division of the third harmonic exciting ampere-turns between them must be inversely as their respective leakage impedances. Hence, having obtained the division of current by test, the division of the leakage impedance between the two windings follows as indicated.

The foregoing method was tested on a three-phase bank of two-legged core-type transformers having a

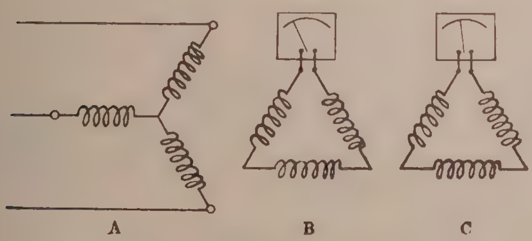

FIG. 9

number of concentric windings on both of the legs. One set of windings was connected in Y for excitation, and two sets were connected in delta, (Fig. 9). The two delta windings had the same current and voltage rating and had low impedance between them, their 60-cycle leakage reactance being about three times their resistance. Both of the delta windings were on one and the same leg of the core. The Y primary windings were chosen on the same leg as the delta windings in one set of tests (marked Case I. below), and on opposite leg in another set of tests (marked Case II. below), to observe the effects of low and high reactances between the primary winding and the two secondary delta windings, with results as follows:

	Nominal flux density in core.	Third harmonic circulating current in each unit in per cent of the total third harmonic current. Delta B	Delta C
Case I.	38 Kilolines/sq. in.	51 per cent	49 per cent
	112 " " "	44 per cent	56 per cent
Low Reactance			
Case II.	43 " " "	48 per cent	52 per cent
	113 " " "	53 per cent	47 per cent
High Reactance			

It is of interest to note how the division of current (and reactance) changes with a change in core density, and also how the direction of change with high reactance primary is opposite from that with low reactance primary. It may be remembered from earlier discussion that this is really a four-winding problem,—three real and one fictitious windings, and that the treatment of this as a three-winding problem, that is as two real (delta) windings and one fictitious winding representing the core, is justifiable only at the lower densities, where the primary exciting current and the corresponding flux in air are small, as confirmed by the fact that Cases I. and II. given above approach each other at the lower density.

THE VIEWPOINT OF FLUX DISTRIBUTION AND LINKAGES

Discussion of reactances by transformer engineers is frequently expressed in terms of flux linkages. This is the designers point-of-view, and has its uses in the determination of losses. As this involves a more detailed analysis of the transformer, one might be led to consider it more basic and accurate. However, as ordinarily handled, it has serious limitations. For instance, a common statement by transformer specialists is that most of the reactance of a transformer, (say 80 per cent to 90 per cent) is primary reactance and that only a small portion, (say 10 per cent to 20 per cent) is secondary reactance. Such a view, although conceding the relativity of individual reactances by assigning the reactance primarily to the excited winding, fails by not distinguishing between main and leakage fluxes and their composite. The basis commonly cited for the assignment of the total or major part of the reactance to the excited winding is briefly as follows: Ignoring the small resistance drops of the windings for simplicity, the net flux-linkages of each winding must be proportional to its terminal voltage. But on the impedance test the secondary terminal voltage is zero, and hence its net flux-linkages must be zero. This condition, however, does not require that no portion of the secondary should link any flux. Since windings must have some thickness, and leakage flux

within their thickness, partial flux-linkages of the short-circuited secondary cannot be avoided, the magnitude and sign of these partial linkages being such as to add up to zero. In making such an analysis it is found that the major part of the flux links exclusively the excited winding, a small part links both the excited winding and the short-circuited secondary, and another small part (equivalent and opposite to the preceding) links exclusively the short-circuited secondary. Basing the resolution of reactance on such a resolution of fluxes, if net flux-linkages alone are considered all reactance becomes primary and none secondary; and if the partial exclusive flux-linkages of the secondary are featured, a small fraction of the total reactance becomes secondary. However, this plausible reasoning fails by confusing the total short-circuit flux with the leakage flux. The flux distribution and linkages hinted above are true only for the resultant of the main and leakage fluxes, and therefore the distribution or linkages of the latter cannot be considered a direct measure of the distribution of the leakage reactance. It would be erroneous to assume that there is no main flux under the impedance test condition, even ignoring the resistance of the windings. Main and leakage components of the flux may cancel in the short-circuited winding, and add up in the excited winding, as illustrated in Figs. 10a and 10b; but the fact that the linkages of the *resultant* flux with the secondary is zero could not be taken as a proof that the leakage reactance of that winding is zero, as this can be proven only by segregating the leakage flux proper and determining its linkages. The two component fluxes, under the impedance test condition, are so intimately merged into each other that their segregation, if attempted by measurements made on the composite flux, is most discouraging, as has been the experience of many an investigator[4]. The practical solution of the problem would rest in making measurements under conditions

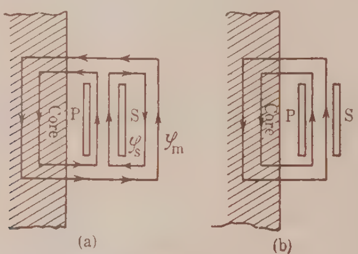

FIG. 10

in which only one kind of flux exists at a time: (a), leakage flux unmixed with main flux in one case; (b), main flux unmixed with leakage flux in the other. Condition (a) is realized by connecting primary and secondary windings in series-opposition (one to one ratio) in which case no exciting current and hence no main flux can exist. Condition (b) is realized by open-circuiting the secondary, so that no load current, and hence no leakage flux, can exist, and impressing on the primary a voltage equal to the secondary impedance drop measured in the preceding case. One small limitation must be borne in mind that due to the different permeability of the core at different densities, the flux distribution and linkages for the resultant flux will not follow exactly the calculated values based on linear combinations of the two components.

CONCLUSIONS

(1) The idea of individual leakage reactance for circuits inductively related to each other is a very convenient conception for certain purposes; however, the resolution is not inherent and absolute, but is purely relative, and is workable only when the problem is theoretically resolvable into three circuits. With less than three circuits, the resolution is indeterminate; and with more than three circuits, it is not possible.

(2) In a two-winding transformer, such a resolution can have a significance only with respect to the exciting current. The resolution is then defined (in terms of three-winding theory) by conceiving the exciting current as caused by a load in a fictitious third winding.

(3) As a practical definition, the individual reactances of a two-winding transformer may be defined as the apparent individual reactances of the two windings in series-opposition connection, on the basis of 1:1 ratio. Other methods of test are also described in the text, but perfect agreement among the various methods cannot be expected on account of the varying permeability of the core at the different densities involved. The different densities will influence the division of reactance very sensibly, even though they may not affect the total reactance appreciably.

(4) In a three-winding transformer, it is not rigorously possible to assign a definite individual leakage reactance to each winding with reference to exciting current, but it is possible to do so with reference to their load currents.

(5) Flux distribution and linkages under the short-circuit test condition apply to the resultant of a main flux and a leakage flux and therefore may not be taken as a direct measure of the division of leakage reactance between primary and secondary windings.

4. See for instance, K. B. McEachron, "Magnetic Flux Distribution in Transformers," JOURNAL A. I. E. E., 1922, pp. 281-287.

It may be noted that in the simple case of a perfectly symmetrical magnetic circuit (ignoring the resistance and thickness of the secondary), the main flux ϕ_m and the leakage flux ϕ_s (shown in Fig. 10A for the impedance test condition) wipe out each other bodily where they fall together, as in the return leakage field of the secondary, and the resultant flux in this region becomes zero, as shown in Fig. 10B. In actual transformers, the distribution of main and leakage fluxes in the return field are neither alike nor uniform, and, therefore, although the two will still neutralize one another's total linkages, they will not wipe out each other's fluxes at every point in the return path of the secondary leakage field, and some of the secondary leakage flux will retain its identity. It is this partial flux which is sometimes erroneously taken as the measure of secondary leakage reactance.

The Measurement of Electrical Output of Large A-C. Turbo-Generators During Water-Rate Tests

BY EVERETT S. LEE[1]

Associate, A. I. E. E.

Synopsis:—*The water-rate of large a-c. turbo-generators is determined in place with the generator supplying power to the existing commercial load. Such procedure requires that the electrical output be accurately measured under conditions where the load is practically always varying slightly, and where it may be varying considerably. Portable test meters are frequently used for such measurement. The use of portable indicating wattmeters is absolutely feasible for such measurement even where the load variations are extreme, with the resultant accruing advantage that the superior operating characteristics of the portable indicating wattmeters, particularly as regards their permanency, are utilized.*

Either the two-wattmeter or three-wattmeter method for measuring the power of a three-phase circuit may be employed.

Great care should be used in selecting instruments, particular reference being made to their past history. Comparisons against secondary standards should be made under conditions simulating those of the test.

Observations are made at frequent intervals depending upon the accuracy desired in the final result.

The accuracy of the final values of water-rate obtainable in practise is such that the per cent average deviation from the mean will be within ± 0.25 per cent. This means that practically all individual test results will fall in a belt 1 per cent wide, while the probably true value of water-rate will be located within a belt which will vary in width from 0.5 per cent to 0.25 per cent depending upon the conditions.

The results of a water-rate test on a highly variable load wherein the electrical output was measured with portable indicating wattmeters and the observations were obtained both with moving-picture cameras and by observers show the equality of the performance of the observers and the cameras under the existing conditions.

Introduction

This paper describes the methods used in measuring the electrical output in forty series of water-rate tests during the past five years on thirty-one machines located in twenty different power plants in this country. The machines tested ranged in rating from 10,000 kw. to 45,000 kw., and the test loads were the usual commercial loads supplied by the respective machines.

These tests were either guarantee acceptance tests or were for purposes of determining the improvement in water-rate produced by advance in machine design. Measurements of maximum possible accuracy were thus required and all means known to the art for attaining such results were available for use as far as they could be applied under the conditions imposed when testing on commercial loads.

Instrument Connections

The usual load being connected three-phase, the three-wattmeter method was used in practically all of the series of tests because of its symmetry. The connections are shown in Fig. 1. The generator neutral being available in practically all large turbo-generators, the connections for the three-wattmeter method are easily made, a set of instruments being connected into each phase. Values of phase voltage, current, and power are thus measured directly, from which measurements the phase power factor can be readily calculated. These values are required for making the necessary corrections to the readings of the wattmeters. Since the phase power unbalance is usually not more than two or three per cent, the three sets of instruments are operating under practically identical conditions which is an advantage both when comparing the instruments and applying corrections, and in operating with them. There is no disadvantage as regards measurement, however, if the phase unbalance is large, as the phase values are directly measured in each case. Since the phase power factor is the same as that at which the wattmeters are operating, and since the former is rarely

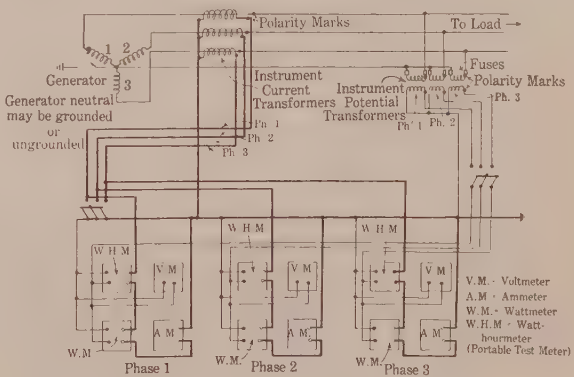

Fig. 1—Diagram of Connections and Table Layout for Measuring Electrical Power in a Three-Phase Circuit Using the Three-Wattmeter Method

less than 0.8, the wattmeters are operating under their best condition which is near to unity power factor.

The two-wattmeter method was used in some series of tests. The connections are shown in Fig. 2. The two-wattmeter method requires less equipment and one less observer than the three-wattmeter method, but it is not symmetrical because the phase relation between the current and voltage supplied to the respective wattmeters differs from that of the load, and is different in

1. General Engineering Laboratory, General Electric Co., Schenectady, New York.

Presented at the Regional Meeting of Dist. No. 1, Swampscott, Mass., May 7-9, 1925.

the respective wattmeters. The actual conditions as regards the current, voltage, and phase relation between them for the individual wattmeters can be determined from the well-known relations existing when measuring three-phase power by the two-wattmeter method. These values must be known when determining the conditions under which the wattmeters are to be compared, and when correcting the wattmeter readings later during test. Except at unity power-factor load the indications of the two wattmeters will be at different portions of the scales; this requires that consideration be given the wattmeters individually as to the suitability of scale range. When the load power factor is 0.8, current lagging, and load balanced, the low-

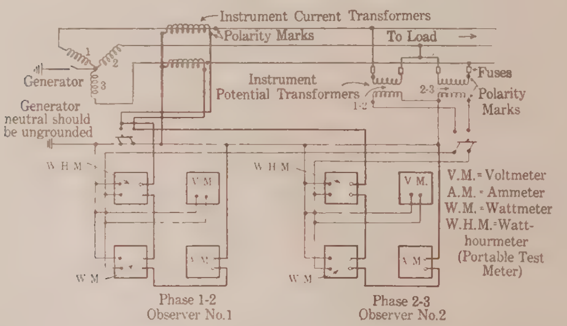

Fig. 2—Diagram of Connections and Table Layout for Measuring Electrical Power in a Three-Phase Circuit Using the Two-Wattmeter Method

reading wattmeter is operating at a power factor of 0.39. This is not at the best operating point of a wattmeter as regards power factor. If the generator neutral is grounded and a ground occurs at any other point on the system, the power may not be correctly measured. For this reason the generator neutral should be ungrounded during test.

Experience does not indicate that there is any real difference in the overall accuracy of a water-rate determination whether the three-wattmeter method or the two-wattmeter method is used, provided that the existing conditions are determined and the proper corrections made for same in each method. Where a large number of series of tests are to be made under widely varying conditions, it is felt that these conditions can be determined and the necessary corrections applied more easily when using the three-wattmeter method. For this reason the latter method has been generally used, in spite of the increased equipment and additional observer required, and the uniformly satisfactory results obtained thereby have justified this selection.

Instruments

Portable indicating wattmeters have been chosen for measuring the electrical output because of their superior characteristics, particularly as regards their permanency. Portable test meters have usually been used in parallel with the indicating wattmeters as shown by the connections Figs. 1 and 2. This was done to study the operating characteristics of both indicating instruments and portable test meters.

For water-rate tests, where sustained accuracy is required, instruments exhibiting the most permanent calibration characteristics should be used. In order to select such instruments from any group available, they should be compared regularly with secondary standards and a careful record should be maintained of all such comparisons made. By means of such a record over a number of years the instruments of greatest permanency will be disclosed. Such a procedure is of greatest importance and should be regularly followed, especially with the wattmeters. Table I shows the results of successive comparisons made upon a portable indicating wattmeter thus selected from a group of similarly made instruments. The wattmeter was carried from laboratory to laboratory by messenger. The results show no difference practically greater than 0.1 of 1 small scale division. This is typical of the performance possible from selected instruments. From such a proof of permanency of calibration possible in high-grade portable indicating wattmeters, the surety for sustained high accuracy throughout a series of tests is evident.

Having selected the instruments, it is necessary that they be compared against secondary standards, under

TABLE I

SUCCESSIVE COMPARISONS OF PORTABLE INDICATING WATTMETER, RATED 5/10 AMPERES, 150/300 VOLTS, 500/1000/1000/2000 WATTS. COMPARISONS MADE ON 5-AMPERE 150-VOLT CIRCUIT

Standardizing Laboratory. Location. Date.	G. E. Co. Schenectady N. Y. 9-13-20	G. E. Co. Pittsfield Mass. 9-16-20	G. E. Co. Schenectady N. Y. 9-18-20	G. E. Co. Erie Pa. 9-20-20	G. E. Co. Cleveland Ohio 9-22-20	G. E. Co. Ft. Wayne Ind. 9-25-20	G. E. Co. Schenectady N. Y. 10-8-20	G. E. Co West Lynn. Mass. 10-11-20	Bureau of Standards Washington D. C. 10-22-20	G. E. Co. Schenectady N. Y. 10-29-20
Watts	Instrument Reads									
0	0	0	0	0	0	0	0	0	0	0
50	50.0	50.0+	50.0	no observation	50.5−	51.0	50.0	50.25	50.7	50.25
100	100.5	100.5	100.0+	100.0+	100.5−	100.5	100.0+	100.5−	100.8	100.5
200	200.0	200.5	200.0	200.0+	200.0−	199.5+	200.0	200.0	200.0	200.0−
300	300.0	300.0	300.0	300.0	300.0	300.5−	300.0	300.0	300.2	300.0
400	400.0	400.0	400.0	401.0	399.5	400.0	400.0−	399.5	399.9	400.0−
500	500.5	500.5	500.5+	500.0	500.5+	501.5+	500.5	501.0	501.2	500.5+

0.1 of 1 small scale division is 0.5 watts

conditions simulating test conditions. Ammeters and voltmeters should be compared at major scale points, with preferably the same kind of current and voltage to be measured during test. Wattmeters may be compared using direct voltage and current by using the average of direct and reversed readings. This assumes that previous measurements have been made on the instruments and standards employed to assure the correctness of such procedure. The value of the voltage maintained on the potential circuit of the wattmeter during comparison should be the test value. The interconnections of the potential and current coil maintained during the comparison should be likewise maintained during test. The value of the phase angle of the potential circuit of the wattmeter requires consideration, though in all high-grade wattmeters this is quite small, such as three to five minutes, and may usually be neglected without error in final result.

Attention should be directed to the small scale divisions of the wattmeters to see that these are properly located. A scale wherein the small scale divisions are improperly located should be replaced with a scale properly made. As mentioned above, when using the two-wattmeter method, one wattmeter may be indicating at the lower end of the scale; it is necessary, under these conditions, that the scale be open at the lower end.

In order to be assured that there is no heating error in the wattmeters due to continuous operation during the water-rate test, comparisons should be made at the beginning and end of a heat run on the wattmeters at normal voltage and maximum current to be measured. If a heating error is found, correction should be made for same by using the comparison obtained with the instrument hot and then allowing the instrument to become hot before use in test. However, the best high-grade portable wattmeters have practically a zero heating error, and such instruments should be used during all tests where maximum accuracy is required.

If watthour meters are to be used, they should be calibrated and adjusted in the laboratory so as to have their best operating characteristics in the range of test values. However, the accuracy curve employed for correction during test, should be obtained "in-place" using the test current and voltage. This should be done with portable indicating wattmeters during the water-rate test. The connections shown in Figs. 1 and 2 allow for such "in-place" checks to be made. Two-minute runs, with the observer reading the indicating wattmeter as rapidly as possible, which will give 40 to 60 observations per minute, are suggested as necessary and sufficient.

A frequency indicator, or other instruments as desired, may be included in the instrument test circuit.

Instrument current and potential transformers of proper rating and accuracy characteristics should be chosen. Values of ratio and phase angle for the condition of loading equivalent to the instruments, meters and leads used during test should be obtained by recognized means to cover the range of test values of current and voltage.

All instruments should be compared immediately before and immediately after the test series. Intermediate tests at two-week intervals may be advisable if the test series is long. Instrument transformers usually need to be calibrated only once during the test series, preferably immediately preceding it. Watthour meters must be calibrated "in-place," preferably immediately before and immediately after each individual test.

Observations

The instruments having been carefully selected and compared for the test conditions, they are connected into the generator line leads as shown either in Figs. 1 or 2. After checking over connections, and comparing the test-instrument readings with the available switchboard-instrument readings to see that there are no major errors, everything is ready to run a test as regards the measurement of electrical output.

Testing on commercial loads requires that means be provided for determining the readings of the indicating wattmeters over a wide range of load conditions. The load may be extremely variable, as in some railway systems, or quite steady as in a large system of combined power and lighting. The means employed has been to take a large number of observations during the test on the theory that if the number of observations is sufficiently large, the average value obtained therefrom will be accurate to within the desired limit, and experience has justified this procedure.

The uniformly satisfactory results of many tests indicate that a test of one-hour duration is ample. Table II shows results to substantiate this conclusion. If it is felt that the conditions at hand warrant tests of longer duration, several tests should be run at the longer duration and the results for each hour of the run be calculated. Such results will indicate whether the necessity for tests longer than one hour is justified. If such is the case, it is quite possible that some of the test conditions are not right and should be altered. In this connection it should be remembered that three one-hour tests at any load point run non-consecutively, are of greater value than three one-hour tests run consecutively.

The observers for the indicating instruments should be men who are capable of comprehending the nature of the work they are doing and who recognize that their efforts should be directed towards obtaining an honest answer as to the value of the water-rate of the machine under test. Their contribution to this effort is recording the readings of the indicating instruments as they honestly believe them to be. Experience obtained with high school graduates, college undergraduates and graduates, and construction men of mature years, indicates that any of these types of men are equally suitable as observers during a test series including some

dozen or two dozen tests and continuing for one or two weeks. The instructions given to all observers are as follows:

1. Place yourself so that you are comfortable and can see the instrument scale without hindrance.

2. Study the appearance of the instrument scale, pointer, and mirror, and have these fixed so clearly in mind that you can look at them and see them with the same familiarity as you would a book or newspaper.

3. Read the position of the pointer on the scale over its image in the mirror just as you see it when you look at it at the designated signal with both eyes open. Read freely and without constraint. Record the value observed.

4. At all other times rest the eyes by looking around as desired. Do not try to average readings during an interval.

5. Do not allow your readings to be influenced by any preconceived ideas as to what the value is probably going to be. Record the result just as it appears to you at the time.

Each observer is assigned to one group of instruments. Each observer reads the indicating wattmeter at a given signal, such as a bell. Unless the observers are widely separated, no preliminary signal is necessary. Instruments are read in regular order, the wattmeter first, followed by the ammeter and voltmeter. The two latter instruments need be read only at every other signal, or in some cases, every fifth signal. Watthour meters are read at the beginning and at the end of every test.

A relief observer will be necessary. The relief can be utilized also to read the values of field voltage and current, which as a rule need be read only at five-minutes intervals during a one-hour test. A supervisor is necessary, together with an assistant who acts as calculator. There are thus required four observers, one calculator, and a supervisor. The supervisor will have to help the calculator after the completion of a days run when the observers are released.

The supervisor and the observers will have to co-operate in order that the supervisor may help the observers to do their work and to detect undesirable tendencies in making observations. Rotating the observers is good practise. A good way to compare observers is, unknown to them, to connect all of the

TABLE II

WATER-RATE FOR EACH HOUR OF TESTS OF LONGER THAN 1-HOUR DURATION

Water-rate for each hour is expressed in per cent of the water-rate obtained from the test, which value is expressed as 100 per cent

Turbo-Generator Designation Number	Test Designation Number	Duration of Test	Water-Rate (Expressed on basis of 100% for Test Value)				Maximum Difference From Test Value Expressed In Per cent	Type of Load
			For Test	1st Hour	2nd Hour	3rd Hour		
1	1	2 Hrs.	100	100.0	99.8		0.2	Rapidly Fluctuating Railway Load
1	2	2 Hrs.	100	99.8	100.2		0.2	
1	3	2 Hrs.	100	100.9	99.2		0.9	
1	4	2 Hrs.	100	100.1	100.0		0.1	Steady Lighting and power load
2	1	3 Hrs.	100	100.3	100.0	99.8	0.3	
2	2	3 Hrs.	100	100.1	100.0	99.8	0.2	
2	3	2 Hrs.	100	100.0	100.0		0.0	
3	1	3 Hrs.	100	100.2	99.9	99.6	0.4	
3	2	3 Hrs.	100	100.2	99.9	99.9	0.2	Steady Lighting and Power Load
3	3	3 Hrs.	100	99.9	100.2	99.9	0.2	
3	4	3 Hrs.	100	99.9	100.2	99.9	0.2	
3	5	3 Hrs.	100	100.0	100.0		0.0	
3	6	2 Hrs.	100	100.0	100.0		0.0	
3	7	2 Hrs.	100	100.1	100.0		0.1	
3	8	2 Hrs.	100	100.0	99.9		0.1	

TABLE III

RESULTS OBTAINED BY CONNECTING ALL INSTRUMENTS IN SERIES UNKNOWN TO THE OBSERVERS

Turbo Generator Designation Number	Duration of Test in Minutes	Time Interval between Readings	Load Conditions	Observers A, B, C			Max. difference in per cent between results obtained by individual observers		
				Phase 1	Phase 2	Phase 3	Wattmeters	Ammeters	Voltmeters
4	60	1 min.	moderately	A	B	C	0.04	1.13*	0.45*
4	60	1 min.	variable	C	A	B	0.25	0.72*	0.27*
4	60	1 min.		B	C	A	0.11	1.78*	0.27*
4	6	15 sec.	moderately	A	B	C	0.20	0.52	0.36
4	5	15 sec.	variable	B	C	A	0.28	0.50	0.27
4	5	15 sec.		C	A	B	0.84	0.48	0.27
5	5	15 sec.	steady	A	B	C	0.33	0.41	0.31
6	2	2 sec.	steady	A	B	C	0.30		
6	2	2 sec.	lighting	A	B	C	0.06		
6	4	4 sec.	and	A	B	C	0.46		
6	10	20 sec.	power	A	B	C	0.40	1.00	0.30
6	10	20 sec.	load	A	B	C	0.40	0.85	0.25

*Ammeter and voltmeter read every two minutes

instruments in series on one set of current and potential transformers. Then run for a convenient time interval, preferably an hour, as during a test, and compare the results obtained by the individual observers. Results from such a procedure are shown in Table III.

The frequency of observation necessary has been determined from the following rule: Readings shall be taken at such intervals during a test that the average of all the observations does not differ from the average of all the alternate observations by more than an assigned value depending upon the accuracy desired. For most accurate results under practical conditions a value of 0.1 per cent has been adopted. For most commercial loads this value has been attained on one-hour tests by taking readings every minute. Table IV shows some results in this connection.

TABLE IV

DIFFERENCE BETWEEN AVERAGE OF ALL THE OBSERVATIONS AND AVERAGE OF ALL THE ALTERNATE OBSERVATIONS

Turbo-Generator Designation Number	No. of tests	Duration Hours	Time Interval between Readings Seconds	Load Conditions	Percent Difference between all Observations and all the alternate Observations, for the number of tests indicated			Method of Measuring
					Average	Maximum	Minimum	
1	27	4 tests, 2 hrs. 23 tests, 1 hr.	10	Rapidly fluctuating Railway load	0.20	0.72	0.01	3-wattmeter
7	5	1	30	Very Steady	0.06	0.10	0.00	2-wattmeter
8	6	1	30	Very Steady	0.14	0.20	0.04	2-wattmeter
5	4	1	60	Steady Lighting	0.11	0.15	0.05	3-wattmeter
9	7	1	60	Steady Lighting	0.12	0.16	0.08	3-wattmeter
4	11	1	60	Variable unbalanced	0.44	1.10	0.01	3-wattmeter
6	11	1	60	Steady Lighting	0.20	0.62	0.02	3-wattmeter
3	3	1	60	Steády Lighting	0.18	0.39	0.07	3-wattmeter

Calculations

The average kilowatt output for any test is the sum of the corrected readings of the wattmeters. The corrected reading for each wattmeter for any test is equal to

$$W \times C.T. \times P.T. \times P_h$$

where: W is the average of all the corrected indications of the wattmeters, expressed in kilowatts. The correction used for each wattmeter is the average of all the comparisons which are made between it and the secondary standards.

$C.T.$ is the true ratio under test conditions of the current transformer to which the wattmeter is connected.

$P.T.$ is the true ratio under test conditions of the potential transformer to which the wattmeter is connected.

P_h is the combined correction factor for phase angle of the current and potential transformers and wattmeter.[2]

The kilowatt-hour output for any test is equal to the product of the average kilowatt output and the duration of the test in hours.

2. See "Revised Tables of Correction Factors for Phase Angle," C. T. Weller, *General Electric Review*, March 1925, and "Handbook for Electrical Engineers," *2nd Edition*, 1922, by H. Pender, Page 1929.

If when comparing any wattmeter the comparison at any point differs from the correction which has been used for previous corrections at this point by more than an assigned value (for most accurate work, taken to be 0.3 per cent of full scale value), an additional comparison or comparisons should be made immediately at this point until their results do not differ among themselves by more than 0.1 per cent of full scale value, and the average of these results will then be taken as the value of the point in question at the time of this comparison. In the event that the excess variation (0.3 per cent of full scale value) still remains, the new value found shall be taken as correct, and all tests in which this scale point may cause error should be investigated to determine the amount to which they have been affected. Such tests may have to be rejected. With the best, high-grade, portable indicating instruments now available, it has been found that the need for this procedure will be rare. However, a statement of such procedure is advisable for guidance if needed. Table V shows the results of successive comparisons of a wattmeter before, during, and after a test series including the suggested heat run. The test series was that described later in this paper (See Section entitled "Photographic Observation,") dated from Jan. 3, to Jan. 31, 1924, and the wattmeter was one of those read by observers. The perfromance of this wattmeter shows what has been found to be typical of high-grade portable indicating wattmeter performance during many test series.

Accuracy of Final Result

A value of accuracy of the final result of the electrical output alone may be arrived at from a knowledge of the precision of the wattmeters and instrument transformers used. However, a more satisfactory accuracy figure, is one which can be applied to the overall measurement of the water-rate of the turbo-generator. This figure is the percent average deviation from the mean, (defined below), and is applied to the results obtained from three or more tests at any given load point.[3] Enough tests can be run at any load point to

3. See "Discussion of the Precision of Measurements" by Silas W. Holman. Second Edition, 1904, chapter on "Direct Measurements."

TABLE V

SUCCESSIVE COMPARISONS OF PORTABLE INDICATING WATTMETER, RATED 5/10 AMPERES, 150 VOLTS, 500/1000 WATTS

Place	Schenectady	Interborough Rapid Transit Company				Schenectady	
Compared by	Gen. Eng. Lab.	Electrical Testing Laboratories				Gen. Eng. Lab.	Maximum Change Small Scale Divisions
Date	12-13-23	1-3-24	1-3*-24	1-17-24	1-31-24	2-11-24	
Scale	Instrument Readings						
0	0	0	0	0	0	0	0
10	9.96		10.0	9.9	10.0	9.92	0.10
15	14.96		15.0	15.0	15.0	14.88	0.12
20	19.94	19.9	20.0	19.9	19.9	19.92	0.10
25	24.94		25.0	24.9	24.9	24.98	0.10
30	29.90		29.9	29.9	29.9	29.92	0.02
35	34.96		35.0	35.0	35.0	35.00	0.04
40	39.94	40.0	40.0	40.0	40.0	39.98	0.06
45	44.96		45.0	45.0	45.0	44.98	0.04
50	49.94		50.0	50.0	50.0	49.98	0.06
55	54.95		55.0	55.0	55.0	55.00	0.05
60	59.94	60.0	60.0	59.9	60.0	60.00	0.10
65	64.94		65.0	65.0	65.0	64.94	0.06
70	70.00		70.0	70.0	70.0	70.00	0.00
75	74.98		75.0	75.0	75.0	75.00	0.02
80	80.00	80.0	80.1	80.1	80.1	79.98	0.12
100	99.90	100.0	100.1	100.0	100.0	99.96	0.20

*Comparison made after a four-hour heat run at 400 watts, 100 volts

bring the value of the percent average deviation from the mean within any desired value. It has been found that a value within $\pm$ 0.25 per cent can be attained in water-rate tests wherein the measurements of electrical output are taken as are described herein and where equal care is given in making the steam-input measurements and corrections. Any individual test at a given load whose value of water rate differs from the mean value of all tests at that load by more than 0.75 per cent may be rejected. It is assumed in the above discussion that all determinate errors have been eliminated and that only indeterminate errors remain.

The percent average deviation from the mean is given by the formula:

$$\text{Per cent } A.D. = \frac{(d_1 + d_2 + d_3 + d_n)\,100}{A\,N\,\sqrt{N}}$$

where A is the average of the values of water-rate obtained from

N tests

N is the number of tests

and $d_1 = W\,R_1 - A$

$d_2 = W\,R_2 - A$

$d_n = W\,R_n - A$, etc.

where $W\,R_1$, $W\,R_2$, $W\,R_n$ are the values of water-rate obtained on the 1st, 2nd and succeeding tests. The absolute values of d_1, d_2, and d_n, are used regardless of sign.

Table VI shows accuracy data from several water-rate tests on large a-c. turbo-generators. The values in the column headed "Percent maximum difference between values of water-rate obtained from tests at each load," show that practically all individual test results fall within a belt one per cent wide. The values in the column headed "Percent average deviation from the mean," show that the probably true value of water-

TABLE VI

PER CENT MAXIMUM DIFFERENCE BETWEEN VALUES OF WATER-RATE FOR SEVERAL TESTS AT A GIVEN LOAD, AND PER CENT AVERAGE DEVIATION FROM THE MEAN

Turbo-Generator Designation Number	Load Kilowatts	Number of tests at each load	Per cent Maximum difference between values of water rate obtained from tests at each load	Per cent average deviation from the mean	Type of Load
10	15,000	8	0.37	±0.09	Steady, lighting and power
	20,000	4	0.29	±0.09	
	25,000	8	0.77	±0.12	
	30,000	9	0.87	±0.08	
11	15,000	2	0.65	±0.32	Slightly variable
	20,000	2	0.19	±0.07	
	23,000	2	0.10	±0.04	
	28,000	5	0.90	±0.11	
12	23,000	2	0.49	±0.18	Slightly variable
	28,000	2	0.61	±0.29	
13	15,000	2	1.13	±0.40	Slightly variable
	20,000	2	0.00	±0.00	
	23,000	2	0.70	±0.25	
	28,000	2	0.71	±0.22	
14	10,000	3	0.66	±0.18	Steady, lighting and power
	15,000	2	0.90	±0.32	
	20,000	2	0.38	±0.13	
	25,000	4	0.00	±0.00	
	30,000	3	0.00	±0.00	
	35,000	2	0.00	±0.00	
15	10,000	3	0.00	±0.00	More variable
	15,000	4	0.18	±0.04	
	20,000	3	0.00	±0.00	
4	15,000	4	0.53	±0.11	More variable
	20,000	8	1.91	±0.18	
	25,000	4	0.09	±0.02	
	30,000	3	0.00	±0.00	
16	23,000	4	0.21	±0.05	Steady, lighting and power
	30,000	4	0.42	±0.15	

rate is located within a belt varying in width from 0.5 per cent to 0.25 per cent depending upon the conditions.

Photographic Observation

This paper would not be complete without a description of the method whereby Messrs. Kidder and Hall of the Interborough Rapid Transit Co. of New York measured the electrical output of a turbo-generator by means of portable indicating wattmeters, the observations of which were made with moving picture cameras. The use of a second set of portable indicating wattmeters in parallel with the test wattmeters, and read by observers, gave opportunity to determine the effectiveness of the observers.

The photographic measurement was made by mounting an indicating wattmeter in a vertical position together with a moving picture camera so focused that the scale of the instrument covered the entire width of the film. The wattmeter was provided with a special pear-shaped target pointer, and was properly balanced for operation with the shaft horizontal. Three such

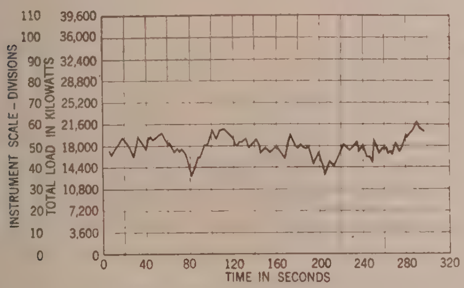

Fig. 3—Load Curve on One-Phase of Turbo-Generator Showing Fluctuations over Instrument Scale

Observations obtained photographically for five minutes of one-second intervals.

instruments and cameras were employed, one set for each phase. The shutter mechanisms of the cameras were operated in synchronism from a common motor-driven drive shaft. Number counters were so mounted on each instrument that the number appeared on the film, thus providing means for identifying all pictures. A watch was photographed on the film at the beginning and at the end of each test to obtain the rate of observation. Suitable illumination was produced from mercury vapor tubes. The entire installation was mounted in the generator room near the machine under test.

The shutter operating mechanism operated the shutters at one-second intervals for short-time duration. For long-time duration such as one-hour test periods, the fastest practicable rate was about one operation per seven seconds, which was the rate maintained during the water-rate tests.

Readings were obtained from the film after development by projecting the image on a screen through a projector and reading the value shown by the pointer. Readings were easily made to within 0.1 small scale division of the wattmeter scale, which is 0.5 watts.

The instruments were compared by setting up secondary standards at the instrument installation in the generator room. Holding scale values on the secondary standard, photographs were taken of the wattmeter indications. After developing the films, the readings were made from the projected image on the screen, and corrections thus obtained. These corrections were later used to correct the wattmeter readings during test. Comparisons were made of the instruments before and

TABLE VII

DIFFERENCE BETWEEN AVERAGE OF ALL OBSERVATIONS AND AVERAGE OF ALL ALTERNATE OBSERVATIONS

G. E. 30,000 Kw. Turbo-Generator, Interborough Rapid Transit Co., New York

Load Kilowatts	Difference between average of all observations and average of all alternate observations, expressed in per cent	
	Photographic Method	Visual Method
13,574	0.47	0.35
14,812	0.29	0.30
15,535	0.66	0.18
16,439	0.06	0.05
18,316	0.17	0.07
18,333	0.16	0.48
19,300	0.14	0.72
19,275	0.19	0.33
21,441	0.09	0.20
21,468	0.23	0.45
23,802	0.14	0.05
23,881	0.17	0.04
24,700	0.03	0.01
25,524	0.06	0.01
25,674	0.06	0.01
25,412	0.18	0.14
26,135	0.01	0.01
27,510	0.07	0.06
27,131	0.11	0.21
28,198	0.18	0.15
26,935	0.07	0.25
27,998	0.12	0.15
27,891	0.11	0.16
29,618	0.09	0.09
29,527	0.05	0.42
29,989	0.29	0.31
29,598	0.18	0.20
Maximum..........	0.66	0.72
Minimum..........	0.01	0.01
Average............	0.16	0.20

after the test series, and intermediate to these at two-week intervals. A preliminary heat run was also made, as previously indicated. The comparisons were all made by the Electrical Testing Laboratories, New York.

The wattmeters used in parallel with the test instruments were compared at the same time as the test instruments except that they were read by observers. Observations were made during test following the principles as described herein. Readings were made at 10-second intervals. Tests were of one-hour duration,

there being three tests each day for nine days during a period of four weeks. At no time did the observers complain of fatigue.

TABLE VIII

PER CENT AVERAGE DEVIATION FROM THE MEAN OF INDIVIDUAL TESTS FOR EACH LOAD POINT

G. E. 30,000 Kw. Turbo-Generator, Interborough Rapid Transit Co. New York

Load Kilowatts	Number of Tests	Per cent Average Deviation from Mean of Individual Tests: Photographic Method	Visual Method
14,000	2	±0.79	±0.78
16,000	2	±0.25	±0.21
18,000	2	±0.19	±0.02
20,000	2	±0.34	±0.22
22,000	2	±0.13	±0.09
24,000	3	±0.21	±0.24
26,000	4	±0.22	±0.27
28,000	6	±0.27	±0.28
30,000	4	±0.17	±0.21
Average (omitting 14,000 kw.).....		±0.22	±0.20
Average (including all loads).......		±0.28	±0.26

Fig. 3 shows a typical curve of the Interborough Rapid Transit Company's load. This is a railway load, and the continual variation was the reason for employing photographic means for obtaining accurate observations. This load is undoubtedly the most variable of the large commercial loads in this country, and results obtained thereon may be taken as representative of the attainment possible under the worst of conditions as regards variable load.

TABLE IX

DIFFERENCE BETWEEN WATER-RATE AS FINALLY ACCEPTED, AND WATER-RATE AS DETERMINED PHOTOGRAPHICALLY AND VISUALLY

G. E. 30,000 Kw. Turbo-Generator, Interborough Rapid Transit Co. New York

Load Kilowatts	Final Accepted Water Rate Expressed as 100 per cent	Water rate by photographic method, expressed as a percentage of final accepted water rate	Water rate by visual method expressed as a percentage of final accepted water rate
14,000	100	100	99.8
16,000	100	99.9	99.7
18,000	100	100.05	99.9
20,000	100	100.1	100.05
22,000	100	100.1	100.1
24,000	100	100.05	100.05
26,000	100	100.	99.95
28,000	100	100.15	99.95
30,000	100	100.1	100.
Differences in Per cent			
	Between photographic and visual	Between photographic and finally accepted	Between visual and and finally accepted
Maximum.......	0.2	0.15	0.3
Minimum.......	0.0	0.0	0.0
Average.........	0.1	0.07	0.1

The performances of the photographic method and the visual method are best shown by Tables VII, VIII and IX. These speak for themselves and show the truly remarkable results that may be obtained on a highly variable load with portable indicating wattmeters both as read with cameras and with observers. The equality of the results obtained by the two methods is evident. The art of electrical measurements is indebted to Messrs. Kidder and Hall for their persistent efforts in overcoming the difficulties in the photographic method, and in carrying it through to a successful conclusion.

Conclusion

The water-rate of large a-c. turbo-generators can be determined with such accuracy that the percent average deviation from the mean, as defined, will be within ± 0.25 per cent. This means that practically all individual test results will fall in a belt one per cent wide, while the probably true value of water rate will be located within a belt varying in width from 0.5 per cent to 0.25 per cent, depending upon the conditions. Such results as these can be obtained on commercial loads, even when the load fluctuations are violent, by using portable indicating wattmeters read by observers following the methods herein described for measuring the electrical output, and with commensurate care in making the steam-input measurements and corrections.

The author wishes to acknowledge the helpful guidance of Mr. L. T. Robinson[4] in carrying on with the tests described in this paper, as well as the assistance received from Messrs. L. J. Cavannaugh and W. S. Vogel of the General Engineering Laboratory of the General Electric Company in conducting the electrical measurements in many of the tests. J. L. Roberts, of the Turbine Department of the General ElectricCo., deserves great credit for his contribution to this work being in charge of the water-rate tests. The effective cooperation of the personnel in the Central Stations where tests were made was also most cordial and helpful, and their contribution to this work is hereby acknowledged.

4. See papers by Mr. L. T. Robinson as follows:

"Testing Steam Turbines and Steam Turbo-Generators," E. D. Dickinson and L. T. Robinson. TRANSACTIONS A. I. E. E., 1910, Vol. XXIX, part II, page 1679.

"The Determination of Stray Losses from Input-Output Tests," L. T. Robinson. TRANSACTIONS A. I. E. E., 1913, Vol. XXXI, part I, page 531.

PROPOSED HYDROELECTRIC DEVELOPMENT IN URUGUAY

The possibility and advisability of developing the hydroelectric resources of the Rio Negro, which bisects the Republic of Uruguay from the northeast to the southwest, has again received the attention of the National Administrative Council, and has been given considerable space in the public press. Uruguay is a country without fuel. The present annual imports of coal and fuel oil are valued at about $8,000,000.

Initial and Sustained Short-Circuits in Synchronous Machines

Analytical and Graphical Treatment of General Cases of Armature Windings Displaced by Arbitrary Angles, with Applications to One-, Two- and Three-Phase Machines

BY VLADIMIR KARAPETOFF[1]
Fellow A. I. E. E.

Synopsis.—*A knowledge of the instantaneous values of armature and field currents, when an alternator is short-circuited, is becoming of increasing practical importance. These currents determine the rating of protective apparatus, mechanical stresses in the machine itself, possible damage to other equipment, etc. During the first few cycles, immediately after a short-circuit, the currents are usually much larger than those on sustained short-circuit, and gradually approach the latter values over a number of cycles. It is, therefore, necessary to distinguish between the initial and sustained values of currents, and formulas are deduced in this paper for both. The novel feature of the treatment consists in starting with a generalized unsymmetrical three-phase winding, also containing an external inductance in one of the phases. The Kirchoff equations are written and solved for this general case, and it is then shown how the formulas for the usual one-, two-, and three-phase machines can be directly derived from the general expressions, without considering the magnetic linkages in detail in each case. A graphical interpretation of the equations is also given, in the form of space-vector diagrams, in which the m. m. f s. vary according to the sine law in space but not in time.*

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INTRODUCTION

THE purpose of the paper is to deduce general formulas for the field and armature currents in a synchronous machine on initial and sustained short-circuit. While the subject is by no means new, the present treatment is perhaps more general than those published heretofore (See Appendix XII).

In a companion paper by R. F. Franklin, entitled "Short-Circuit Currents of Synchronous Machines," emphasis is laid upon the important practical cases, and the formulas are illustrated by calculated curves of currents. In the present paper, emphasis is laid upon the general method of derivation, and specific cases are carried out only far enough to show that the results check with Franklin's work.

In accordance with the preference of the Institute readers, the paper, itself, is made short and non-mathematical, while the details of derivation of the formulas are placed in the appendices to which references are made in the text.

THE DIAGRAM OF CONNECTIONS

Figs. 1 and 2 show a three-phase winding of a synchronous machine, in which, for the sake of generality, the electrical angles between the phases are assumed to be different from 120 deg. Moreover, each phase winding is assumed to possess a different number of turns and therefore a different inductance (for notation, see Appendix XIII). An external inductance, L, is shown in series with one of the armature windings, and equations are derived with this inductance in the circuit. By putting $L = 0$, an ordinary three-phase short-circuit is obtained; by putting $L = \infty$. the phase C is opened and a single-phase short-circuit is obtained between the phases A and B.

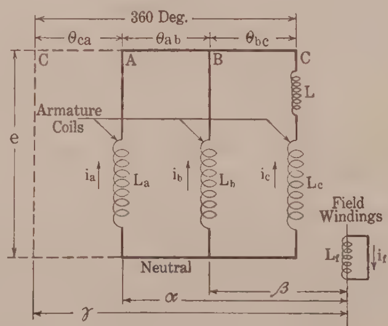

FIG. 1—GENERALIZED UNSYMMETRICAL THREE-PHASE WINDING

The field winding is assumed to be placed on a cylindrical rotor, so that the self and mutual inductances of the armature windings may be considered to remain constant throughout a cycle. Moreover, the mutual

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inductances between the field and the armature windings have been assumed to vary harmonically (Appendix I).

The resistances of all the windings are neglected altogether. For this reason, the field winding is shown in Fig. 1 short-circuited upon itself, since the excitation voltage is only necessary for overcoming the resistance of the winding. A certain field current is assumed to exist at the instant of short-circuit, and then to vary only under the influence of the armature currents so as to keep the flux linkages constant; equations (**4**) and (**25**).

The assumption of zero resistances is justified during the first half cycle or so after the instant of short-circuit, when the magnetic fluxes essentially determine the currents. With large alternators, this assumption is also justified for the armature windings on sustained short-circuit, the ohmic drop being practically negligible. The resistances of the windings enter as a factor in the gradual adjustment of the currents from the initial values to those on sustained short-circuit. This transitional period is not considered in the paper.

By neglecting the resistances, it becomes possible to

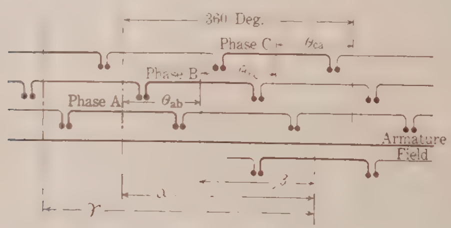

FIG. 2—THE RELATIVE POSITION OF THE ARMATURE AND FIELD WINDINGS

integrate directly the Kirchoff equations (**1**) to (**4**). With resistance terms, the corresponding simultaneous differential equations become practically unsolvable. A few attempts to solve them even approximately in the simplest cases have led to expressions which are too complicated for practical use. The method of successive approximations, although quite tedious, may possibly be applied with more success.

Having obtained the fundamental equations, (**1**) to (**5**), for the general case shown in Fig. 1, and integrated them in the form of equations (**22**) to (**25**), various special cases are considered in the subsequent appendices, as indicated below.

SINGLE-PHASE SHORT-CIRCUIT

The most general case of single-phase short-circuit considered in this paper is that through an external inductance (Appendix V). The angle, θ_{ab}, is put equal to zero and the windings in the phases A and B are assumed to coincide, so as to form but one winding. The current flows through this combined winding, through the inductance L, and through the phase winding C. Since the angle, θ_{bc}, is not necessarily equal to 180 deg., this case covers not only a short-circuit of a single-phase machine, but a single-phase short-circuit of a polyphase machine as well.

More specific cases are then considered in detail in Appendix VII, with the assumption $L = 0$. For the single-phase machine $L_c = 0$; for a two-phase machine the inductance L_c is equal to the parallel combination of L_a and L_b, and $\theta_{bc} = 90$ deg.; for a three-phase machine $\theta_{bc} = 120$ deg. The final formulas are shown to check with those in Franklin's paper. Finally, a graphical interpretation of the single-phase short-circuit is given in Appendix XI.

POLYPHASE SHORT-CIRCUIT

The general expressions for the armature and field currents, equations (**22**) to (**25**), are first interpreted graphically, as shown in Fig. 4 (Appendix III). This figure gives a much clearer idea of the inter-relationship of the currents than the equations themselves. It is then shown in Appendix IV that when $L = 0$ and $L_c > 0$, the voltage e (Fig. 1) between the terminals and the neutral, is always equal to zero. This leads to a simplification of Fig. 4 to Fig. 6, and the corresponding equations are derived in Appendix VI. These equations are then applied to the usual two-phase and three-phase machines in Appendix VIII, and the results are shown to check with Franklin's formulas.

INDIVIDUAL VS. COMMON SHORT-CIRCUIT

With two-phase and three-phase short-circuits, several cases have to be considered, as shown in Figs. 7 and 8. In the Appendix IX, it is shown that the cases 7 *a* and 7 *b* are electrically equivalent, and that identical currents may be expected in both, at least within the limits of the fundamental assumptions made in the paper. Similarly, the cases 8 *a* and 8 *b* are identical, but the case 8 *c* presents some additional features. The influence of the ohmic resistance and of the character of the mutual inductance between the phases is discussed, and the conclusion is reached that at least in usual alternators the currents in case 8 *c* may be expected to be approximately equal to those computed for the cases 8 *a* and 8 *b*.

CONCLUSION

The determination of short-circuit currents in synchronous machines is of considerable importance to the designer as well as to the operating engineer. These currents may cause considerable mechanical stresses in the machine, influence the selection of the protective equipment, determine the transient conditions in the connected lines, etc.

The fundamental equations with which this investigation begins (Appendix I), are of quite general application, and it is hoped that the mathematical portions of the paper, especially the general method, may be of service not only in cases in which the equations or their solutions actually apply, but also in other cases, (for example, in an induction machine), in which simi-

lar equations may be established and a similar method of solution used.

Mr. R. E. Doherty, of the General Electric Company, suggested this investigation as a sequel to his own well-known researches in the subject, and the author wishes to acknowledge, gratefully, his encouragement and assistance in the preparation of the paper. Mr. K. C. Mobarry read and corrected the manuscript and made several valuable suggestions, for which the author wishes to express to him his gratitude.

Appendix I

The Fundamental Equations

Referring to Fig. 1, let at an instant (t) the voltage between the neutral points be (e). Then, equating to (e) the total e. m. f. induced in phase (A), we have,

$$L_a\, d\, i_a/d\, t + M_{ab}\, d\, i_b/d\, t + M_{ca}\, d\, i_c/d\, t + d\,(M_{fa}\, i_f)/d\, t = e \qquad (1)$$

For notation, see Appendix XIII. The coefficients of mutual induction, M_{ab} and M_{ca}, do not vary with the time and therefore, are left outside the sign of the derivative. The coefficient of mutual induction, M_{fa}, between the field winding and the armature phase (A), is a function of time and, therefore, a derivative must be taken of the linkages, $M_{fa}\, i_f$.

By analogy, we can write for phases (B) and (C), respectively, with a cyclic substitution of the subscripts (a), (b), (c):

$$L_b\, d\, i_b/d\, t + M_{bc}\, d\, i_c/d\, t + M_{ab}\, d\, i_a/d\, t + d\,(M_{fb}\, i_f)/d\, t = e \qquad (2)$$

$$(L_c + L)\, d\, i_c/d\, t + M_{ca}\, d\, i_a/d\, t + M_{bc}\, d\, i_b/d\, t + d\,(M_{fc}\, i_f)/d\, t = e \qquad (3)$$

In equation (3), $(L_c + L)$ is used instead of (L_c), where (L) is the external inductance. (L) is not interlinked magnetically with any of the phases, and therefore does not enter in the other equations. For the field circuit, we have;

$$L_f\, d\, i_f/d\, t + d\,(M_{fa}\, i_a)/d\, t + d\,(M_{fb}\, i_b)/d\, t + d\,(M_{fc}\, i_c)/d\, t = 0 \qquad (4)$$

The first Kirchoff law, applied to the armature winding, gives,

$$i_a + i_b + i_c = 0 \qquad (5)$$

Equations (1) to (5) contain five unknown functions of time (t); namely, i_a, i_b, i_c, i_f, e; by solving the equations, all these functions can be determined.

The foregoing equations can be somewhat simplified by expressing the inductances through the corresponding equivalent permeances and the numbers of turns[2]. Moreover, with the fluxes and m. m. f's. assumed to be distributed sinusoidally along the airgap, the various mutual inductances are simple cosine functions of the angles of separation between the two coils.

Let the permeance of the useful (or common) magnetic path through the field and the armature be $(\mathcal{P})$ henries. Let τ be the magnetic leakage coefficient of the field circuit, that is, let,

$$\tau = \Phi_{useful}/\Phi_{total} \qquad (6)$$

when the field alone is excited. Similarly, let (σ) be the magnetic leakage coefficient of the armature winding. Both (σ) and (τ) are less than unity. The four self-inductances can be expressed as follows:

$$L_a = \sigma^{-1}\, \mathcal{P}\, N_a^2;\; L_b = \sigma^{-1}\, \mathcal{P}\, N_b^2;\; L_c = \sigma^{-1}\, \mathcal{P}\, N_c^2 \qquad (7)$$

$$L_f = \tau^{-1}\, \mathcal{P}\, N_f^2 \qquad (8)$$

It is convenient to assume the external inductance coil (L) to have the same number of turns as one of the phase windings, for example phase (A), and to represent its equivalent permeance in the form, $k\, \sigma^{-1}\, \mathcal{P}$, so that,

$$L = k\, \sigma^{-1}\, \mathcal{P}\, N_a^2 \qquad (9)$$

The factor (k) may have any positive value between zero and infinity, so that equation (9) in no way limits the value which may be assigned to (L).

The simplest assumption which can be made in regard to the coefficients of mutual inductance is that they are harmonic functions of the space angles between the coils. This approximately holds true for machines in which the armature m. m. f. is distributed in space in accordance with the sine law. Let the coils in phase (B) be shifted until they completely coincide with the coils in phase (A). Then, the coefficient of mutual inductance between the two is equal to $\mathcal{P}_m\, N_a\, N_b$, where $\mathcal{P}_m$ is the mutual or common permeance of the magnetic circuit embraced by the two groups of coils. When the coils completely coincide, $\mathcal{P}_m = \sigma^{-1}\, \mathcal{P}$. Now, as the coil (B) is moved back to its true position, we may assume that the part of the flux due to (A) and linking with (B) varies as the cosine of the angle of shift. The mutual permeance varies in the same ratio. With these assumptions, we obtain the following expressions for the various M' s;

$$M_{ab} = \sigma^{-1}\, \mathcal{P}\, N_a\, N_b \cos\theta_{ab} \qquad (10a)$$

$$M_{bc} = \sigma^{-1}\, \mathcal{P}\, N_b\, N_c \cos\theta_{bc} \qquad (10b)$$

$$M_{ca} = \sigma^{-1} \mathcal{P}\, N_c\, N_a \cos\theta_{ca} \qquad (10c)$$

$$M_{fa} = \mathcal{P}\, N_a\, N_f \cos\alpha \qquad (11a)$$

$$M_{fb} = \mathcal{P}\, N_b\, N_f \cos\beta \qquad (11b)$$

$$M_{fc} = \mathcal{P}\, N_c\, N_f \cos\gamma \qquad (11c)$$

The coefficient of mutual inductance, M_{fa}, reaches its maximum when $\alpha = 0$. By definition, the coefficient of magnetic coupling, K, is determined from the relationship,

$$K^2 = (\max.\, M_{fa})^2/(L_f\, L_a) \qquad (12)$$

Substituting the values from equations (7), (8), and (11a), we get, after reduction,

$$K^2 = \sigma\,\tau \qquad (13)$$

The variable angles α, β, γ, differ from each other by constant amounts; namely,

$$\beta = \alpha - \theta_{ab} \qquad (14)$$

$$\gamma = \alpha + \theta_{ca} \qquad (15)$$

2. V. Karapetoff, "The Magnetic Circuit," p. 184.

Instead of t, we shall take α for the independent variable, where

$$\alpha = \omega t = 2 \pi f_0 t \tag{16}$$

We then have,

$$d/dt = \omega . d/d\alpha = \omega . d/d\beta = \omega . d/d\gamma \tag{17}$$

It is convenient to represent (e) in equation (1) as a derivative of some function with respect to time, because then the equation can be integrated directly. We, therefore, put,

$$e = \sigma^{-1} \mathcal{P} N_a^2 \, d s/d t \tag{18}$$

where (s) is a function of time, containing no constant term. However, any desired constant term may be added to (s) without changing the value of e in equation (18). We shall arbitrarily assume that this constant term is zero so that $s = 0$ when $e = 0$. The factors σ, N_a^2, and $\mathcal{P}$ are added in order later to cancel them on both sides of certain equations.

The following assumptions are further made:

(a) The coils (A) and (B) have the same number of turns (N), so that,

$$N_a = N_b = N \tag{19}$$

(b) The number of turns in coil (C) is (c) times that in (A); in other words,

$$N_c = c N \tag{20}$$

The factor (c) may have any value between zero and infinity.

(c) The number of turns in a field coil is (f) times that in the coil (A), so that,

$$N_f = f N \tag{21}$$

Substituting the foregoing expressions in equations (1) to (4), we obtain, after integration and simplification:

$$i_a + i_b \cos \theta_{ab} + c\, i_c \cos \theta_{ca} + f \sigma i_f \cos \alpha = s + A \tag{22}$$

$$i_b + c\, i_c \cos \theta_{bc} + i_a \cos \theta_{ab} + f \sigma i_f \cos \beta = s + B \tag{23}$$

$$(c^2 + k)\, i_c + c\, i_a \cos \theta_{ca} + c\, i_b \cos \theta_{bc} + c f \sigma i_f \cos \gamma = s + c C + [k I_c] \tag{24}$$

$$i_a \cos \alpha + i_b \cos \beta + c\, i_c \cos \gamma + f \tau^{-1} i_f = F f \tau^{-1} I_f \tag{25}$$

Here, (A), (B), (C), (F), are constants of integration; for the initial short-circuit conditions, they depend upon the values of the currents and of (s) at the instant of short-circuit. In order to make the initial constant (C) independent of (k), the term $k I_c$ is added in equation (24). This term is placed in the brackets to indicate that it is used only for the initial short-circuit. With a sustained or established short-circuit, the currents are independent of the initial values, such as I_c, and the term $k I_c$ is simply omitted.

Equations (22) to (25), together with equation (5), contain five unknown functions of the time-angle (α), namely i_a, i_b, i_c, i_f, s, and can be solved for these as simultaneous equations.

Appendix II

Constants of Integration

1.—*Armature Constants for the Initial Short-Circuit.* For the instant of short-circuit, equations (22) to (24) become

$$U \cos \xi = S + A \tag{26}$$

$$U \cos (\xi - \theta_{ab}) = S + B \tag{27}$$

$$c\, U \cos (\xi + \theta_{ca}) = S + c C \tag{28}$$

where

$$U \cos \xi = I_a + I_b \cos \theta_{ab} + c I_c \cos \theta_{ca} + f \sigma I_f \cos \alpha_0 \tag{29}$$

$$U \cos (\xi - \theta_{ab}) = I_b + c I_c \cos \theta_{bc} + I_a \cos \theta_{ab} + f \sigma I_f \cos \beta_0 \tag{30}$$

$$U \cos (\xi + \theta_{ca}) = c I_c + I_a \cos \theta_{ca} + I_b \cos \theta_{bc} + f \sigma I_f \cos \gamma_0 \tag{31}$$

In equation (29), the initial linkages on the right-hand side are arbitrarily denoted by $U \cos \xi$. Granting this notation, the other two equations can be deduced as follows:

Let I_a, I_b, I_c, I_f and U be thought of as vectors (in space, *not* in time.) Then equation (29) may be thought of as the real part of the expression

$$U \epsilon^{j\xi} = I_a \epsilon^{jo} + I_b \epsilon^{j\theta_{ab}} + c I_c \epsilon^{-j\theta_{ca}} + f \sigma I_f \epsilon^{j\alpha_0} \tag{32}$$

Multiplying this equation throughout by $\epsilon^{-j\theta_{ab}}$, and equating the real parts, equation (30) is obtained. Multiplying both sides of equation (32) by $\epsilon^{j\theta_{ca}}$ and equating the real parts, gives equation (31).

To solve equations (29) to (31) for (U) and (ξ), use equation (32), since it gives, directly, the values of $U \cos \xi$ and $U \sin \xi$. Dividing the second value by the first will give $\tan \xi$ and consequently $\cos \xi$. (U) is then found by dividing the expression for $U \cos \xi$ by $\cos \xi$.

In the actual solution of equations (22) to (25), the first step is to eliminate (s) by subtraction. Consequently, it is also convenient to eliminate (S) from equations (26) to (28). We then get[3]

$$B - A = 2\, U \sin 0.5\, \theta_{ab} \sin (\xi - 0.5\, \theta_{ab}) \tag{33}$$

$$A - c C = U b \sin (\xi + \theta_{ca}') \tag{34}$$

where

$$b \sin \theta_{ca}' = 1 - c \cos \theta_{ca} \tag{35}$$

$$b \cos \theta_{ca}' = c \sin \theta_{ca} \tag{36}$$

Equation (34) is deduced as follows: Subtracting equation (28) from equation (26), we get

$$U [\cos \xi - c \cos (\xi + \theta_{ca})] = A - c C \tag{37}$$

Expanding the expression in the parentheses and introducing the quantities (b) and θ_{ca}', according to the defining equations (35) and (36), gives:

$$U [b \cos \xi \sin \theta_{ca}' + b \sin \xi \cos \theta_{ca}'] = A - c C \tag{38}$$

3. The symbol (b) appearing in equations (35) and (36), and later in equations (66) and (67), has nothing to do with phase (B), but is an auxiliary constant defined by these equations.

From this expression, equation (**34**) follows directly. A geometric interpretation of the auxiliary quantities (b) and θ_{ca}' is shown in Fig. 3. $(A\,C)$ represents the phase (A), with the number of turns arbitrarily assumed to be equal to unity. To the same scale, $(A\,B)$ represents the winding of the phase (C), with the number of turns (c) times that of phase (A). The space angle between the windings is θ_{ca}. The closing line of the triangle $(A\,B\,C)$ represents (b), and the angle which it forms with the normal to $(A\,C)$ is equal to θ_{ca}'. Equations (**35**) and (**36**) are then satisfied. We also have

$$b^2 = 1 + c^2 - 2\,c \cos \theta_{ca} \qquad \textbf{(38a)}$$

$$\tan \theta_{ca}' = (1 - c \cos \theta_{ca})/(c \sin \theta_{ca}) \qquad \textbf{(39)}$$

When $$I_a = I_b = I_c = 0 \qquad \textbf{(40)}$$

equations (**29**) to (**31**) simply become

$$U = f\,\sigma\,I_f; \quad \xi = \alpha_0 \qquad \textbf{(41)}$$

with the corresponding simplification of equations (**33**) and (**34**).

Because of the form (**41**) to which the expression for (U) is reduced in the simplest case, it is convenient for some purposes to put generally:

$$U = u\,f\,\sigma\,I_f \qquad \textbf{(42)}$$

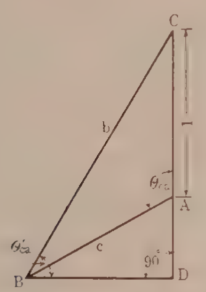

FIG. 3—DEFINITION OF THE AUXILIARY QUANTITIES B AND θ_{ca}

where (u) is a proper factor to make equation (**42**) agree with equations (**29**) to (**31**).

It is shown in Appendix IV that when $k = 0$, (s) is equal to zero at all instants, so that (S) is also equal to zero. Equations (**26**) to (**28**) are then simplified accordingly.

2.—Armature constants for the permanent short-circuit.

In this case, omitting the term $[k\,I_c]$ in equation (**24**), we simply have:

$$A = B = U = 0 \qquad \textbf{(43)}$$

and $$C = 0 \qquad \textbf{(44)}$$

for the following reasons: The armature currents i_a, i_b, i_c in equation (**22**), can have no d-c. component, because the phenomenon now consists in an established operation of the alternator, all transients having died out. Hence, the average value of each current over a cycle is equal to zero; since

$$\text{average } i = (2\,\pi)^{-1} \int_0^{2\pi} i\,d\,\alpha$$

we have, $$\int_0^{2\pi} i\,d\,\alpha = 0 \qquad \textbf{(44a)}$$

The field current, i_f, has a d-c. component and (we may provisionally assume) has some sinusoidal harmonics. However, a sine-wave component of fundamental frequency is absent because it could be induced only by a stationary armature flux or by one moving at twice the synchronous speed. Therefore, expanding the field current into a Fourier series, we have,

$$i_f = i_0 + i_2 \sin (2\,\alpha + \mu_2) + i_3 \sin (3\,\alpha + \mu_3) + \text{etc.}$$

and consequently

$$\begin{aligned} i_f \cos \alpha = {} & i_0 \cos \alpha + i_2 \cos \alpha \sin (2\,\alpha + \mu_2) \\ & + i_3 \cos \alpha \sin (3\,\alpha + \mu_3) + \ldots \\ & + i_n \cos \alpha \sin (n\,\alpha + \mu_n) \qquad \textbf{(44b)} \end{aligned}$$

But,

$$\begin{aligned} \cos \alpha \sin (n\,\alpha + \mu_n) = {} & 0.5 \sin [(n+1)\,\alpha + \mu_n] \\ & + 0.5 \sin [(n-1]\,\alpha + \mu_n]. \end{aligned}$$

Multiplying by $d\,\alpha$ and integrating over a cycle, we get,

$$\int_0^{2\pi} \cos \alpha \sin (n\,\alpha + \mu_n)\,d\,\alpha = 0$$

Hence, if we multiply equation (**44b**) by $d\,\alpha$ and integrate over a cycle, each term on the right-hand side is separately equal to zero, and consequently

$$\int_0^{2\pi} i_f \cos \alpha\,d\,\alpha = 0 \qquad \textbf{(44c)}$$

Therefore, from equations (**44a**) and (**44c**) we see that if equation (**22**) is multiplied by $d\,\alpha$ and integrated over a cycle, each term on the left-hand side is separately equal to zero, so that the right-hand side is also equal to zero.

But, by assumption, (s) has no constant term and consists of sinusoidal terms only, so that its integral over a cycle is equal to zero. Consequently $2\,\pi\,A = 0$ or $A = 0$. By a similar reasoning it can be shown from equation (**23**) that $B = 0$; equation (**44**) can be proved from equation (**24**). The result $U = 0$ follows from equations (**33**) and (**34**).

3.—Field Constant for the Instant of Short-circuit.

The constant of integration (F), in equation (**25**), is determined from the condition

$$\begin{aligned} & (F - 1)\,f\,\tau^{-1}\,I_f \\ & \quad = I_a \cos \alpha_0 + I_b \cos \beta_0 + c\,I_c \cos \gamma_0 \qquad \textbf{(45)} \end{aligned}$$

When the condition (**40**) is satisfied,

$$F = 1 \qquad \textbf{(46)}$$

4.—Field Constant for Permanent Short-Circuit.

Permanent armature currents can induce in the field winding only alternating voltages, without any d-c. component. Hence, the average value of i_f over a cycle is equal to the actual value I_f of the field current at no-load. In other words

$$\int_0^{2\pi} i_f\,d\,\alpha = 2\,\pi\,I_f \qquad \textbf{(47)}$$

Under the assumed conditions, the field current is a periodic function of α; so that, in general, we may write,

$$i_{fp} = m\,F\,I_f\,\phi\,(\alpha) \tag{47a}$$

where the subscript (p) signifies "permanent," (m) is a known constant, and $\phi\,(\alpha)$ is a certain function of the time-angle α. Therefore, equation (**47**) becomes:

$$m\,F \int_0^{2\pi} \phi\,(\alpha)\,d\,\alpha = 2\,\pi \tag{47b}$$

Knowing (m) and $\phi\,(\alpha)$, the factor (F) can be determined from this expression.

In this investigation, only two particular forms of $\phi\,(\alpha)$ occur. Each of these forms permits definite integration and, hence, a solution for (F). For a two-phase or three-phase short-circuit, with $k = 0$, $i_{fp} = I_f$ (see equation **134**), so that it is permissible to put $F = m = \phi\,(\alpha) = 1$. With a single-phase short-circuit, equation (**106**), the function ϕ is of the form:

$$\phi\,(\alpha) = [n - 2\,q\,\sin^2(\alpha - \theta')]^{-1} \tag{48}$$

where n, q, θ', are known constants. Equation (**48**) may also be written as

$$\phi\,(\alpha) = [(n - q) + q\cos 2\,(\alpha - \theta')]^{-1} \tag{48a}$$

Integrating in this latter form, we get[4]

$$\int_0^{2\pi} \phi\,(\alpha)\,d\,\alpha = 2\,\pi / \sqrt{(n - q)^2 - q^2} \tag{49}$$

so that, from equation (**47b**),

$$F_{1p} = m^{-1}\sqrt{(n - q)^2 - q^2} \tag{49a}$$

The subscript $(p\,1)$ signifiees "permanent single-phase short-circuit."

Appendix III

Graphical Representation of the Linkage Equations (22) to (25) in a Polyphase Short-Circuit[5]

Equations (**22**) to (**25**) are represented in Fig. 4 by means of a polygon of *space vectors*. The currents being non-sinusoidal in time, no ordinary time-vector diagrams can be used. However, the distribution of all the m. m. f.'s in space being by assumption sinusoidal, these m. m. f.'s, for a particular instant of time, can be represented by space vectors. For another instant of time, the lengths of the vectors i_a, i_b, i_c, i_f, and the angle (α), are different, but the angles θ_{ab}, θ_{bc}, θ_{ca}, ξ, and the lengths $O\,K$ and $H\,N$ remain constant.

Taking first equation (**22**) and substituting for (A) its value from equation (**26**), we get:

$$\begin{aligned} i_a + i_b\cos\theta_{ab} + c\,i_c\cos\theta_{ca} + f\,\sigma\,i_f\cos\alpha \\ = U\cos\xi + (s - S) \end{aligned} \tag{50}$$

In Fig. 4, $O\,A = i_a$ and $A\,B = i_b$, the space angle (*not* the time angle) between these two m. m. f. vectors being θ_{ab}. Since $i_a + i_b + i_c = 0$, instead of laying off the vector $c\,i_c$ in the direction of i_c, we draw the vector $c\,(i_a + i_b) = B\,C$ in the opposite direction. Let, at the instant shown in Fig. 4, the angle (α) be equal to $A\,O\,P$. In other words, if $O\,A$ represents the axis of an armature coil in phase A, $O\,P$ is the axis of the field coil, revolving clockwise.[6] The vector $C\,G = f\,\sigma\,i_f$ is drawn parallel to $O\,P$ and consequently at an angle α to $O\,A$. The vector $O\,K = U$ makes an angle ξ with $O\,A$. Finally, the vector $K\,A' = s - S$ is drawn parallel to $O\,A$. $K\,A'$ is shown as a chord of a circle drawn on $K\,G$ as a diameter. This is to indicate that $G\,A'$ is perpendicular to $O\,A$. The direction $G\,K$ is extended to L, and a circle is drawn on $K\,L$ as a diameter. The length of this diameter is such that the chord $K\,A'' = S$, where A lies on the same straight line with K and A'. Since $K\,A' = s - S$, we have that $A''\,A' = s$. Thus, by means of the two circles both s and S can be represented separately.

In the polygon $O\,A\,B\,C\,G\,A'\,K$, all the sides, except $A'\,G$, have been expressed through the physical quantities which enter into our problem. If, however, all the sides of the polygon be projected on $O\,A$, the side $A'G$ is eliminated, and we may write that

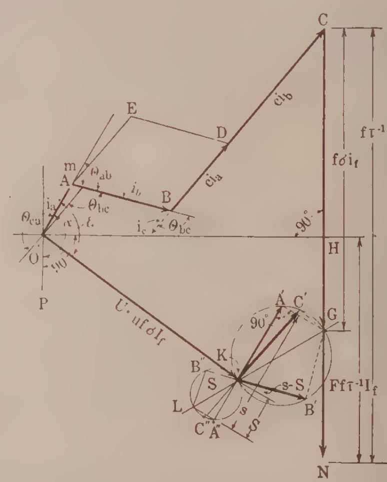

Fig. 4—Space Diagram of the Armature and Field m. m. f.'s.

$$\begin{aligned} &\text{Sum of projections on } O\,A \text{ of } (O\,A + A\,B + B\,C + C\,G) = \\ &\text{Sum of projections on } O\,A \text{ of } (O\,K + K\,A') \end{aligned} \tag{51}$$

A comparison of this equation with equation (**50**) shows the two to be identical, and we conclude that the above-mentioned polygon represents equation (**22**).

By analogy with equation (**50**), equation (**23**) may be written in the form:

$$\begin{aligned} i_b + c\,i_c\cos\theta_{bc} + i_a\cos\theta_{ab} + f\,\sigma\,i_f\cos\beta \\ = U\cos(\xi - \theta_{ab}) + (s - S) \end{aligned} \tag{52}$$

Thus, to represent equation (**23**), it is only necessary to replace $K\,A'$ by $K\,B'$ parallel to $A\,B$. When projecting the new polygon on the direction $A\,B$, the unknown vector $B'\,G$ is eliminated. Since both $K\,A'$ and $K\,B'$ are equal to $s - S$, the angles $A'\,K\,G$ and $B'\,K\,G$ must in reality be equal.

4. See, for example, Peirce's "Short Table of Integrals," p. 41, Equation (**300**), the last line.

5. For a similar representation in the single-phase case see Appendix XI.

6. The counter-clockwise rotation has been standardized for time vectors only, and there is no objection to using the clockwise rotation for space vectors.

To represent equation (**24**), we first eliminate $c\,C$ by using equation (**28**). The result is:

$$c^2 i_c + c\, i_a \cos\theta_{ca} + c\, i_b \cos\theta_{bc} + c\, f\, \sigma\, i_f \cos\gamma = c\, U \cos(\xi + \theta_{ca}) + (s - S) - k\, i_c + [k\, I_c] \quad (53)$$

Here we have to distinguish between the case when $c > 0$ and when $c = 0$. When $c > 0$, both sides of equation (**53**) can be divided by c. The result corresponds to the polygon $O\,A\,B\,C\,G\,C'\,K$, where $K\,C' = (s - S)\,c^{-1} - k\, i_c\, c^{-1} + [k\, I_c / c]$ and is parallel to $B\,C$. When $c = 0$ equation (**53**) is reduced to:

$$s - S = k\, i_c - [k\, I_c] \quad (53a)$$

and permits to eliminate $s - S$ in a simple manner.

The polygon which corresponds to equation (**25**) is $O\,A\,B\,C\,H$, where:

$$C\,H = f\,\tau^{-1}\,(i_f - F\,I_f) \quad (54)$$

The sum of the projections of $O\,A + A\,B + B\,C + C\,H$ upon $O\,P$ is always equal to zero, for any value of angle α. In other words,

$$C\,N + \text{Sum of projections of } (O\,A + A\,B + B\,C) = H\,N \quad (55)$$

This is identical with equation (**25**).

As angle α varies, the directions $O\,A$, $A\,B$, $B\,C$ remain the same, only the values of the currents, and consequently the positions of the points A, B, C, vary. The vector $O\,K$ remains constant in magnitude and in direction. The vector $C\,N$ turns so as to remain parallel to $O\,P$, and its part $H\,N$ remains of constant length equal to $F\,f\,\tau^{-1}\,I_f$. The diameters $K\,G$ and $K\,L$ vary in magnitude and in direction.

When there is no external reactive coil (that is, when $k = O$), $S = s = O$ at all instants, and the voltage between the neutral points remains equal to zero (see proof below). Consequently, both circles in Fig. 4 shrink to zero and the diagram is considerably simplified; see Appendix VI.

Appendix IV

PROOF THAT $s = O$ WHEN $k = O$ AND $c > O$

Multiply equation (**50**) by $c \sin\theta_{bc}$, equation (**52**) by $c \sin\theta_{ca}$ and equation (**53**) by $\sin\theta_{ab}$, and add them together. In the result, the factor by which $c\, i_a$ is multiplied is

$$\sin\theta_{bc} + \sin\theta_{ca}\cos\theta_{ab} + \sin\theta_{ab}\cos\theta_{ca} = \sin\theta_{bc} + \sin(\theta_{ca} + \theta_{ab}) \quad (56)$$

But, according to Figs. 1 and 2,

$$\theta_{ab} + \theta_{bc} + \theta_{ca} = 360 \text{ deg.} \quad (57)$$

so that $$\sin(\theta_{ca} + \theta_{ab}) = -\sin(\theta_{bc}) \quad (58)$$

Therefore, expression (**56**) is identically equal to zero. Similarly, it can be proved that the resulting equation does not contain i_b and i_c.

One of the factors by which $c\, i_f$ is multiplied in the result is:

$$\text{Cos}\,\alpha \sin\theta_{bc} + \cos(\alpha - \theta_{ab})\sin\theta_{ca} + \cos(\alpha + \theta_{ca})\sin\theta_{ab}$$

$$= \cos\alpha\,(\sin\theta_{bc} + \sin\theta_{ca}\cos\theta_{ab} + \sin\theta_{ab}\cos\theta_{ca}) + \sin\alpha\,(\sin\theta_{ab}\sin\theta_{ca} - \sin\theta_{ca}\sin\theta_{ab}) \quad (59)$$

In this expression, the term by which $\sin\alpha$ is multiplied is identically equal to zero, and the term by which $\cos\alpha$ is multiplied is the same as expression (**56**) which we have shown before to be equal to zero. Thus, the resultant equation does not contain i_f. For the same reason the quantity (U) is eliminated. Thus, the result is:

$$(s - S)\,(c \sin\theta_{bc} + c \sin\theta_{ca} + \sin\theta_{ab}) = k\, i_c \sin\theta_{ab} - [k\, I_c \sin\theta_{ab}] \quad (60)$$

If k is not equal to zero then, since i_c is a function of time, (s) is also a function of time. But when $k = O$, s must be equal to (S), where (S) is a constant; consequently, (s) must also be constant. According to equation (**18**), this means that when $k = O$, (e) is also equal to zero, no matter how unbalanaced the phases may be. But, by assumption, (s) contains no constant term; hence, when $k = O$,

$$s = S = O \quad (61)$$

The foregoing deduction, being based on equations (**56**) and (**59**), presupposes that the coefficients of mutual inductance are harmonic functions of space angles; in other words, that equations (**10a**) to (**11c**) hold true. If the winding is such that these relations are not satisfied, or satisfied only approximately, (s) may depart from zero and be a function of time. When equation (**61**) is satisfied, only two out of the three equations, (**22**), (**23**) and (**24**), are independent of each other. The third one can be obtained by properly combining the other two. The same is true of equations (**50**), (**52**), and (**53**). This may be seen directly from Fig. 4. When $S = s = O$, point K coincides with G (Fig. 6) and the closed polygon $O\,A\,B\,C\,G\,K$ is the same for each of the three aforementioned equations. But the condition that a polygon is closed is expressed by stating that the sum of its projections on any two axes is equal to zero. It is superfluous to equate to zero the sum of its projections on any third axis, because the equations so obtained can be written by properly combining the other two equations. This follows from the fact that if the projections of a vector on two given directions are known, its projection on any third direction is also known.

Thus, in this case we have only four equations instead of five, but we also have only four unknown functions; namely, the armature currents and the field current. This case is considered in detail in Appendix VI.

The foregoing deduction, and the condition (**61**), do not necessarily hold true when one of the angles θ is equal to zero. Let, for example θ_{ab} be equal to zero, so that $\theta_{bc} = 360 \text{ deg.} - \theta_{ca}$. Then equations (**50**) and (**52**) become identical and can no more be considered as independent equations. Moreover, both sides of equation (**53**) cannot be multiplied by $\sin\theta_{ab}$, because $\sin\theta_{ab} = O$. From the physical point of view, when any two of the windings,—say A and B,—coincide in space

they form a single phase, with the winding C as the return phase. We thus have a single-phase circuit, the sum of the currents i_a and i_b being considered as one current. The voltage between the neutral and the terminals (Fig. 1) is then not equal to zero, unless $c = O$, that is, unless the phase C is simply a jumper of negligible impedance. This case is further considered in Appendices V and X.

Appendix V

SINGLE-PHASE SHORT-CIRCUIT THROUGH AN INDUCTANCE

Let, in Fig. 1 and 2, the angle θ_{ab} be equal to zero, so that the windings of the phases (A) and (B) coincide. Let the angle θ_{bc} now be simply denoted by θ; then, $\theta_{ca} = 360$ deg. $- \theta$. The currents (i_a) and (i_b) do not exist singly, but their sum is equal to $- i_c$. Equation (**50**) becomes,

$$- i_c (1 - c \cos \theta) + f \sigma i_f \cos \alpha$$
$$= U \cos \xi + (s - S) \qquad (\mathbf{62})$$

Equation (**52**) becomes identical with equation (**62**) and cannot be used. Equation (**53**) becomes,

$$i_c (c^2 - c \cos \theta) + c f \sigma i_f \cos (\alpha - \theta)$$
$$= c U \cos (\xi - \theta) + (s - S) - k i_c + [k I_c] \qquad (\mathbf{63})$$

Equation (**25**) becomes,

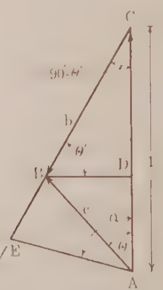

FIG. 5—DEFINITION OF THE AUXILIARY QUANTITIES B AND θ^1

$$f \tau^{-1} i_f + i_c [c \cos (\alpha - \theta) - \cos \alpha] = F f \tau^{-1} I_f \qquad (\mathbf{64})$$

To eliminate ($s - S$), we subtract equation (**62**) from equation (**63**). The result is,

$$i_c [c^2 - 2 c \cos \theta + 1 + k] + f \sigma i_f [c \cos (\alpha - \theta) - \cos \alpha]$$
$$= U [c \cos (\xi - \theta) - \cos \xi] + [k I_c] \qquad (\mathbf{65})$$

In this equation, the expressions within all the brackets can be simplified by introducing auxiliary quantities (b) and (θ'), shown in Fig. 5. ($A C$) is a unity vector; ($A B$) is equal to (c) and is drawn at an angle (θ) to ($A C$). Then, (b) is the closing side of the triangle and (θ') is the angle between (b) and the perpendicular $B D$ to $A C$. Let the direction $A E$ be drawn at an angle α to $A C$. Then, from the geometry of the figure, the angle at E is equal to 90 deg. $+ \theta' - \alpha$, and we have,

$$1 - c \cos \theta = b \sin \theta' \qquad (\mathbf{66})$$
$$c \sin \theta = b \cos \theta' \qquad (\mathbf{67})$$
$$b^2 = c^2 + 1 - 2 c \cos \theta \qquad (\mathbf{68})$$

Multiply equation (**66**) by ($\cos \alpha$) and equation (**67**) by ($\sin \alpha$); subtracting the first result from the second, gives,

$$c \cos (\alpha - \theta) - \cos \alpha = b \sin (\alpha - \theta') \qquad (\mathbf{69})$$

and by analogy,

$$c \cos (\xi - \theta) - \cos \xi = b \sin (\xi - \theta') \qquad (\mathbf{70})$$

Therefore, equation (**65**) becomes,

$$i_c (b^2 + k) + f \sigma b i_f \sin (\alpha - \theta')$$
$$= U b \sin (\xi - \theta') + [k I_c] \qquad (\mathbf{71})$$

while equation (**64**) is reduced to,

$$b i_c \sin (\alpha - \theta') + f \tau^{-1} i_f = F f \tau^{-1} I_f \qquad (\mathbf{72})$$

Solving equations (**71**) and (**72**) for i_c and i_f, we get,

$$i_{f1} = \frac{F I_f [1 + (k/b^2)] - [k I_c] \tau \sin(\alpha = \theta')/(b f) - (U/f) \tau \sin (\xi - \theta') \sin (\alpha - \theta')}{[1 + (k/b^2)] - K^2 \sin^2 (\alpha - \theta')} \qquad (\mathbf{73})$$

$$i_{c1} = \frac{- (F/b) I_f f \sigma \sin (\alpha - \theta') + (U/b) \sin (\xi - \theta') + [k I_c]/b^2}{[1 + (k/b^2)] - K^2 \sin^2 (\alpha - \theta')} \qquad (\mathbf{74})$$

where K^2 is defined by equations (**12**) and (**13**), and the subscript (1) stands for "single-phase." For the determination of the constants, U, ξ, and F, see Appendix II. In particular, for a permanent short-circuit, $U = O$, $I_c = O$, and comparing equation (**73**) with equations (**47 a**) and (**48**), we find that,

$$m = n = 1 + (k/b^2); \quad q = 0.5 K^2$$

Hence, equation (**49a**) will give,

$$F_{p1} = [1 + (k/b^2)]^{-1} .$$
$$\{ [1 + (k/b^2) - 0.5 K^2]^2 - (0.5 K^2)^2 \}^{0.5} \qquad (\mathbf{75})$$

For a graphical interpretation of equations (**71**) and (**72**), see Appendix XI.

RADIO SUNSET FADING TESTS

In special tests from March 24 to April 2, the Bureau of Standards, with the cooperation of about 20 laboratories in various cities, made records of the variation in intensity of signal received from station WGY, General Electric Co., Schenectady, N. Y., during the sunset period. In order to study further the effects of sunset a second series of observations was started May 19 on station KDKA, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa. Records were made by an augmented group of laboratories on six days, distributed during the period May 19 to May 29. The observing periods were approximately three hours long, centering at the time of sunset at the receiving station. The records of these observations as well as those of the tests on WGY are being studied and a report on the characteristic effects which these observations established will be issued at a later date.

Short-Circuit Currents of Synchronous Machines

BY R. F. FRANKLIN*

Associate, A. I. E. E.

Synopsis.—*The importance of short-circuit forces in large alternators has warranted an investigation of them. The first step in this investigation, which is discussed in this paper, is the calculation of the short-circuit currents that produce them. The method of solution used is that of the assumption of zero resistance and constant flux linkages which has proven so useful in the solution of many short-circuit problems. Formulas are calculated in the Appendix for both the initial and permanent short-circuit currents of all circuits involved in the short-circuit. The formulas cover all the common connections of single-phase, two-phase and three-phase alternators. A discussion of some of these formulas, together with a plot of them for assumed alternator constants, is also given.*

Introduction

One of the difficult problems encountered in the design of large alternators is that of providing sufficient strength of the different parts to withstand the forces produced during short circuit. The author participated in an investigation of these short-circuit forces which was begun a couple of years ago and recently completed. The results of this investigation will be given in this and future papers before the Institute.

The short-circuit forces depend largely upon the abnormal short-circuit current that flows in the various windings and can be calculated if the character and magnitude of these currents are known. The first step, therefore, in the calculation of these forces is the calculation of the short-circuit currents that produce them.

Since Bucherot's excellent discussion of alternator short-circuit currents in 1911[1], many papers have been published treating of both the phenomena involved and the method of calculation. A method of solution which has proven useful in the investigation of many short-circuit problems is that of the assumption of zero resistance and constant flux linkages. This method was used in 1918 in a paper by Messrs. R. E. Doherty and O. E. Shirley[2], for an explanation of short circuit phenomena in synchronous machines, and again in 1921 in a paper by Messrs. R. E. Doherty and E. T. Williamson[3] for an investigation of the short circuit current of induction motors and generators. In a recent paper[4] Mr. Doherty again emphasized the importance of this method of interpreting short circuit problems and gave a number of applications. In a more recent paper[5] Mr. C. M. Laffoon applied this method to the calculation of several cases of short circuit of an alternator. It is the purpose of this paper to apply this constant-linkage method to the calculation of both the *initial* and *permanent* short-circuit currents of synchronous machines.

Method of Solution

The constant-linkage method is based on the assumption that the electrical resistance of the various circuits is zero. As a result of this assumption the following *constant-linkage theorem* has been proved[6]: *"In a circuit having zero resistance the algebraic sum of the flux linkages of the circuit must remain constant."* The application of this theorem to the calculation of short-circuit currents is very similar to that of the application of Kirchoff's laws to the solution of networks. First, currents are assumed to flow in the different branches of the circuits. The flux linkages in any branch are those due to the current in that branch and those due to currents in other branches. The flux linkages of each circuit are then summed up and equated to some constant value of flux linkages which is known to exist in the circuit. By solving, simultaneously, these flux-linkage equations expressions for the currents flowing in the different branches of the circuits are obtained.

Results

The various alternator connections and kinds of short-circuit for which formulas are derived are shown by the nine cases in Fig. 1. For each case formulas are derived for both the *initial* and *permanent* short-circuit conditions. A tabulation of the formulas for the various cases of Fig. 1 are given in Table I. These formulas are plotted in Figs. 3 to 14, for assumed alternator constants.

Initial Short Circuit Current

The initial short-circuit current waves, Figs. 3 to 8, show all peaks of the same height since, resistance being neglected, the transient decay of the current wave actually obtained in practise is not present. The instant of short-circuit in each case is so chosen as to give the maximum possible value of current in phase a. The maximum value of current occurs 180 electrical degrees after the instant of short-circuit. During this time the resistance of the circuits, which in the calculations has been neglected, reduces this peak value slightly from that calculated. The formulas thus

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*D. C. Engineering Dept., General Electric Co., Jan. 13, 1925.

1. Bibliography 1.
2. Bibliography 3.
3. Bibliography 5.
4. Bibliography 8.
5. Bibliography 9.

Presented at the Spring Convention of the A. I. E. E., St. Louis, Mo., April 13-17, 1925 and at the Regional Meeting of Dist. No. 1, Swampscott, Mass., May 7-9, 1925.

6. For a proof of this theorem refer to discussion of Mr. R. E. Doherty's paper, Bibliography 5.

give a peak value a little higher than actually obtained in practise. In Table II is given the peak values of the initial short-circuit current for the various cases in terms of the peak value of the current obtained in the three-phase alternator, case 9, in which all three phases are short-circuited simultaneously. It will be observed from Table II that the short-circuit current obtained for a single-phase short-circuit of one phase of a three-phase alternator from one terminal to ground is 150 per cent of the three-phase value. A single-phase short-citcuit between terminals gives only 86 per cent of the three-phase value, and a two-phase short-circuit between two terminals and ground, 173 per cent of the three-phase value.

Permanent Short Circuit Current

In the calculation of the permanent short-circuit current formulas the flux linkage equations of the armature circuits were equated to zero. The reason for this is, that during the transient period of a short-circuit, the flux linkages which are caught by the armature circuits at the instant of short circuit are consumed by the resistance of the circuits. Therefore, when the permanent condition is reached the only flux linkages supplied by the field circuit are those which are being consumed by resistance. If zero resistance is assumed in the permanent condition, then no flux linkages are supplied to the armature circuits by the field circuit and the currents that flow in the armature circuits must be such as to at all times, keep out all field flux linkages. In other words, the flux linkages of each armature circuit must be zero.

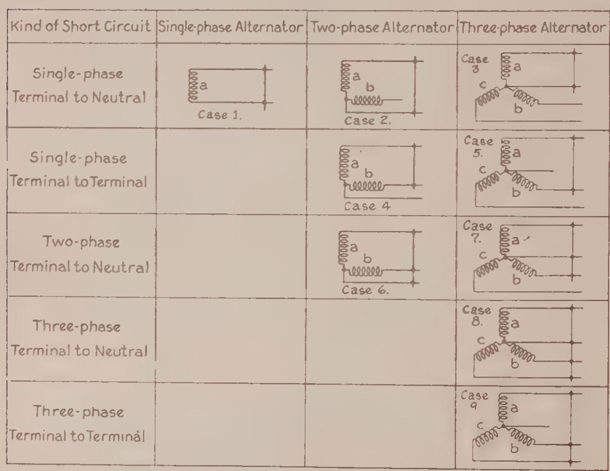


Fig. 1—Cases for Which Initial and Permanent Short Circuit Current Formulas are Derived

The formulas for the permanent condition are plotted in Figs. 9 to 14. The single-phase cases show the characteristic double frequency pulsation in the field current. In Fig. 15 is given an oscillogram of the armature and field current of a three-phase alternator during a permanent single-phase short-circuit between terminals in which the shape of the current waves is very similar to those calculated in Fig. 11.

The field current for the three-phase alternator case with two phases short-circuited between terminals and ground, (Case 7, Fig. 13), does not have any alternating component induced in it. This is due to the fact that the coefficient of inductive coupling between the short circuited phases a and b was assumed in the derivation of the formulas, equal to the cosine of the angle between phases. Thus, for a three-phase alternator, this coupling coefficient was assumed equal to cos 120, or $-$ 0.5. This ideal value of coupling is seldom obtained in practise. The effect of a coupling co-efficient different from $-$ 0.5 on the field current is shown by the oscillogram of Fig. 16. The field current contains an alternating component of double frequency and of about $\pm$ 9 per cent of the d-c. component. This corresponds to a coupling coefficient between phases a and b of about $-$ 0.49. In the study of this phase of the subject formulas were calculated for all cases in which no definite value of coupling coefficient between phases was assumed. These formulas were very complicated compared to the formulas here given. The effect of this coupling coefficient is so slight that it was felt unwarranted to complicate the formulas by making them more general in this respect. For all practical applications the value $-$ 0.5, assumed in the calculation of the formulas, is sufficiently accurate.

TABLE I.
SHORT CIRCUIT CURRENT FORMULAS

Case (See Fig. 1)	Initial Condition		Permanent Condition	
	Formulas	Fig.	Formulas	Fig.
1, 2, 3	(10) (11)	3	(80) (81)	9
4	(23) (24)	4	(86) (87)	10
5	(40) (41)	5	(92) (93)	11
6	(48) (49) (50)	6	(101) (102) (103)	12
7	(57) (58) (59)	7	(110) (111) (112)	13
8, 9	(71) (72) (73) (74)	8	(117) (118) (119) (120)	14

TABLE II.
Comparison of Maximum Peak Values of Initial Short-Circuit Currents. The current values are based on constant conductors per inch.

Case (See Fig. 1)	Maximum Peak Value of Current in Phase a as a Ratio of that obtained in Case 9
1	0.75
2	1.06
3	1.50
1	0 75
5	0.866
6	1 06
7	1.732
8	1.00
9	1.00

Assumptions

The following assumptions were made in the calculation of the formulas:

a. Zero resistance in all circuits
b. Magnetic saturation neglected
c. Sine wave distribution of field flux
d. Constant coefficient of self-inductance of armature phases.
e. Variation of mutual inductance between armature phases as the cosine of the angle between them.

The calculation of alternator short-circuit currents becomes very involved if too many refinements are attempted. Therefore in order to obtain as simple a solution as possible, the above assumptions are necessary. While some of these assumptions may not appear reasonable a careful study of them and a comparison with results in practise reveals that for very many practical problems they can be tolerated.

The assumption of zero resistance was made necessary by the method of solution of the problem. The predominence of reactance over resistance during the short-circuit of an alternator makes it possible to neglect the resistance in this kind of a problem. Assumption *b* should involve greater error, but any attempt to take saturation into account makes the problem very complicated. The error due to saturation can be minimized by taking it into consideration in the calculation of the inductance coefficients. Assumption *c* is very close to present practise in the design of alternators. Assumption *d* involves the neglect of the salient pole feature of alternators since the coefficient of self inductance of the armature phases is not constant but will vary somewhat with the position of the field poles. An investigation of the affect of this variation upon the short circuit currents showed that only a small double frequency current was introduced which did not appreciably effect the results obtained. The effect of *e* has already been discussed. Formulas were calculated for all cases in which the coefficient of coupling between armature phases was not assumed constant. The formulas are greatly complicated by this general assumption. The assumption of − 0.5 for this coupling coefficient which was made in the derivation of the formulas of this paper greatly simplify the formulas and does not introduce appreciable error.

In concluding the author wishes to express his appreciation of the assistance of Messrs. R. E. Doherty and R. . Park and Professor V. Karapetoff in the solution of this problem.

Appendix

Derivation of Short Circuit Current Formulas Initial Condition

1. *Single-phase short circuit.*

(a) Single-phase or polyphase alternator.

One general formula can be obtained for the single-phase short-circuit current of a single-phase, two-phase, or three-phase alternator when only one armature phase is involved in the short circuit. (Cases 1 to 3, Fig. 1). The instant of short circuit will be taken when the armature phase *a* encloses maximum field flux as this is the condition when maximum short circuit current is obtained. This condition occurs when the angle α in Fig. 2A equals zero[7].

There are only two circuits involved; the field circuit and the armature circuit *a*. The flux linkages of these two circuits at the instant of short circuit, *i. e.*, when α equals zero, are respectively[8].

$$\Omega_f = I_f L_f \tag{1}$$

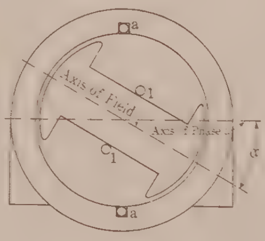
$$\Omega_a = I_f M_0 \tag{2}$$

The flux linkages of these two circuits at any instant after short circuit are,

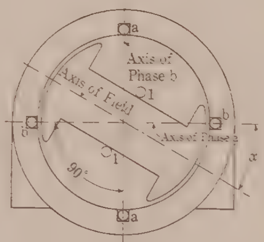
$$\Omega_f = i_f L_f + i_a M_{fa} \tag{3}$$

$$\Omega_a = i_a L_a + i_f M_{af} \tag{4}$$

Applying the constant linkage theorem, the flux linkages at any instant after short-circuit, (3) and (4),



A



B

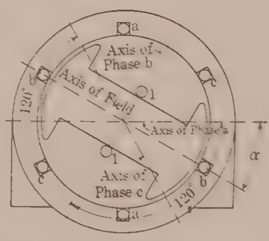


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Fig. 2—Schematic Diagrams Showing the Relations of the Various Alternator Circuits

must equal the flux linkages before short-circuit, (1) and (2) respectively,

$$i_f L_f + i_a M_{fa} = I_f L_f \tag{5}$$

$$i_a L_a + i_f M_{af} = I_f M_0 \tag{6}$$

7. For simplicity a two pole alternator is shown in which case the electrical angle is equal to the mechanical angle.

8. For definition of symbols see Notation.

Solving these two equations simultaneously for the currents i_f and i_a,

$$i_f = I_f \frac{L_f L_a - M_0 M_{fa}}{L_f L_a - M_{fa}^2} \qquad (7)$$

$$i_a = I_f \frac{L_f M_0 - L_f M_{fa}}{L_f L_a - M_{fa}^2} \qquad (8)$$

The inductance coefficients L_f and L_a are assumed constant. The coefficients M_{fa} varies with the rotation of the rotor, and may be approximated by a cosine function; thus[9]

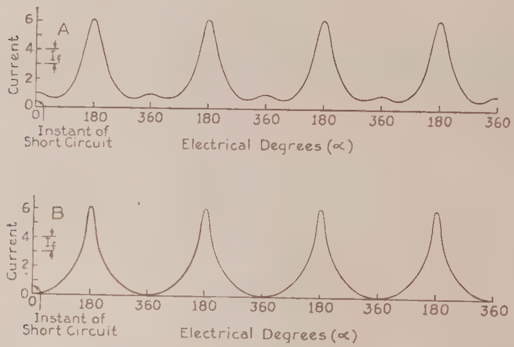

Fig. 3—Initial Short-Circuit Currents; Cases 1, 2 and 3

Curve A—Field current. Eq. (10).
Curve B—Current in phase a. (Eq. 11).

$$M_{fa} = M_{af} = M_0 \cos \alpha \qquad (9)$$

Substituting this relation in (7) and (8) and dividing both numerator and denominator by $L_f L_a$,

$$i_f = I_f \frac{1 - K^2 \cos \alpha}{(1 - 0.5 K^2) - 0.5 K^2 \cos 2 \alpha} \qquad (10)$$

$$i_a = I_f \frac{M_0}{L_a} \frac{1 - \cos \alpha}{(1 - 0.5 K^2) - 0.5 K^2 \cos 2 \alpha} \qquad (11)$$

where, K = coefficient of magnetic coupling between the two circuits

$$= \frac{M_0}{\sqrt{L_f L_a}} \qquad (12)$$

Equations (10) and (11) are plotted in Fig. 3 for

$$K = 0.85 \text{ and } \frac{M_0}{L_a} = 0.85.$$

(b) Two-phase alternators, single-phase terminal to terminal short-circuit, (Case 4, Fig. 1).

In this case there are only two circuits involved since armature phases a and b are connected in series, forming only one circuit $a\,b$. As seen in Fig. 2B the circuit $a\,b$ does not enclose maximum field flux when α equals zero, but when

$$M_{fab} = M_{fa} - M_{fb}$$

is a maximum that is, when

$$\frac{d M_{fab}}{d \alpha} = 0$$

From (9) and the relation

$$M_{fb} = M_0 \cos (\alpha - 90) = M_0 \sin \alpha \qquad (13)$$

$$\frac{d M_{fab}}{d \alpha} = M_0 (- \sin \alpha - \cos \alpha) = 0$$

or $\alpha = -45$ deg.

Therefore, for maximum field flux enclosure by the circuit $a\,b$ the short circuit must occur at $\alpha = -45$ deg. The flux linkages of the field and armature circuits at this value of α are,

$$\Omega_f = I_f L_f \qquad (14)$$

$$\Omega_{ab} = \Omega_a - \Omega_b = I_f M_{af}' - I_f M_{bf}'$$

where, M_{af}' and M_{bf}' are the values of M_{af} and M_{bf} respectively at $\alpha = -45$ deg.

Hence from (9) and (13)

$$\Omega_{ab} = \sqrt{2}\, I_f M_0 \qquad (15)$$

The linkages at any instant after short-circuit are,

$$\Omega_f = i_f L_f + i_a M_{fa} + i_b M_{fb} \qquad (16)$$

$$\Omega_{ab} = \Omega_a - \Omega_b = i_f (M_{af} - M_{bf}) + i_a (L_a - M_{ba}) + i_b (M_{ab} - L_b) \qquad (17)$$

Due to reverse connection of a and b

$$i_{ab} = i_a = - i_b \qquad (18)$$

Thus from (14) (15) (16) (17) and (18)

$$i_f L_f + i_{ab} (M_{fa} - M_{fb}) = I_f L_f \qquad (19)$$

$$i_f (M_{af} - M_{bf}) + i_{ab} (L_a + L_b) = \sqrt{2}\, I_f M_0 \qquad (20)$$

Since, the axes of the phases are at right angles,

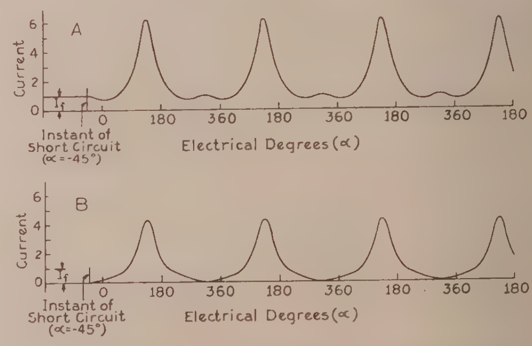

Fig. 4—Initial Short-Circuit Currents; Case 4

Curve A—Field current. Eq. (23)
Curve B—Field current in circuit a b. Eq. (24)

$$M_{ab} = M_{ba} = 0 \qquad (21)$$

Solving (19) and (20) simultaneously and substituting (9), (12), (13) and

$$L_a = L_b \qquad (22)$$

$$i_f = I_f \frac{1 - K^2 \cos (\alpha + 45)}{(1 - 0.5 K^2) - 0.5 K^2 \cos 2 (\alpha + 45)} \qquad (23)$$

$$i_{ab} = \frac{1}{\sqrt{2}} I_f \frac{M_0}{L_a} \frac{1 - \cos (\alpha + 45)}{(1 - 0.5 K^2) - 0.5 K^2 \cos 2(\alpha + 45)} \qquad (24)$$

9. $M_{fa} = M_{af}$ when saturation is neglected.

These currents are plotted in Fig. 4 for $K = 0.85$ and

$$\frac{M_0}{L_a} = 0.85.$$

(c) Three-phase alternator, single-phase terminal to terminal short circuit, (Case 5, Fig. 1).

There are only two circuits to consider, the field circuit f and one armature circuit composed of phases a and b in series. The armature circuit encloses maximum field flux when M_{fab} is a maximum.

This occurs when

$$\frac{d\,M_{fab}}{d\,\alpha} = 0$$

Now since phases a and b are displaced 120 deg. from each other

$$M_{fb} = M_0 \cos(\alpha - 120) \qquad (25)$$

and

$$M_{fab} = M_{fa} - M_{fb} = M_0 [\cos\alpha - \cos(\alpha - 120)] \qquad (26)$$

Differentiating, equating to zero and solving for α,

$$\alpha = -30 \text{ deg.}$$

Thus the instant of short-circuit should be taken at

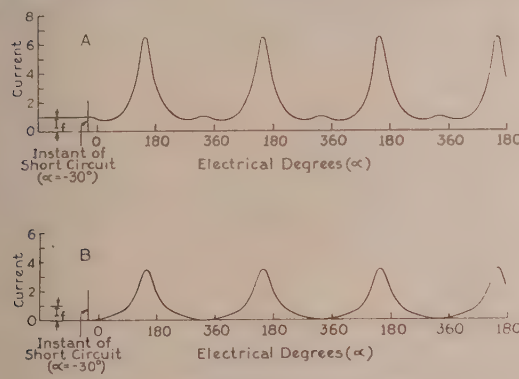

FIG. 5—INITIAL SHORT-CIRCUIT CURRENTS; CASE 5
Curve A—Field current. Eq. (40)
Curve B—Curren in Circuit ab Eq. (41)

$\alpha = -30$ deg. The flux linkages of the two circuits at this instant are,

$$\Omega_f = I_f L_f \qquad (27)$$

$$\Omega_{ab} = \Omega_a - \Omega_b = I_f M_{af}'' - I_f M_{bf}'' \qquad (28)$$

where M_{af}'' and M_{bf}'' are the mutual inductances between the field circuit and phases a and b respectively at $\alpha = -30$ deg.

Thus from (9) and (25)

$$\Omega_{ab} = \sqrt{3}\, I_f M_0 \qquad (29)$$

The flux linkages of the two circuits at any instant after short-circuit are,

$$\Omega_f = i_f L_f + i_a M_{fa} + i_b M_{fb} \qquad (30)$$

$$\Omega_{ab} = \Omega_a - \Omega_b \qquad (31)$$

where,

$$\Omega_a = i_a L_a + i_f M_{af} + i_b M_{ab} \qquad (32)$$

$$\Omega_b = i_b L_b + i_f M_{bf} + i_a M_{ba} \qquad (33)$$

But due to reverse connection of a and b

$$i_{ab} = i_a = -i_b \qquad (34)$$

The coefficient M_{ab} is defined as

$$M_{ab} = k\sqrt{L_a L_b}$$

The coefficient of coupling k depends upon the relative positions of the two phases a and b and may be assumed to vary as the cosine of the angle between their axes. Thus in this case where the angle between phases is 120 deg.

$$k = \cos 120 \text{ deg.} = -0.5$$

and,

$$M_{ab} = -0.5\, L_a \qquad (35)$$

Substituting (34) in (30)

$$\Omega_f = i_f L_f + i_{ab}(M_{fa} - M_{fb}) \qquad (36)$$

Substituting (32) (33) (34) and (35) in (31)

$$\Omega_{ab} = i_f (M_{af} - M_{bf}) + i_{ab}\, 3\, L_a \qquad (37)$$

Equating (27) and (36), and (29) and (37)

$$i_f L_f + i_{ab}(M_{fa} - M_{fb}) = I_f L_f \qquad (38)$$

$$i_f (M_{af} - M_{bf}) + i_{ab}\, 3\, L_a = \sqrt{3}\, I_f M_0 \qquad (39)$$

Solving (39) and (40) simultaneously and substituting (9) (12) and (25),

$$i_f = I_f \frac{1 - K^2 \cos(\alpha + 30)}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2(\alpha + 30)} \qquad (40)$$

$$i_{ab} = \frac{1}{\sqrt{3}} I_f \frac{M_0}{L_a} \frac{1 - \cos(\alpha + 30)}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2(\alpha + 30)} \qquad (41)$$

Equations (40) and (41) are plotted in Fig. 5 for

$$K = 0.85 \text{ and } \frac{M_0}{L_a} = 0.85.$$

2. *Two Phase Short Circuit*

(a) Two phase alternator, (Case 6, Fig. 2)

There are three circuits to consider; the field circuit, phase a and phase b. The flux linkages of these circuits at the instant of short-circuit, *i. e.*, when $\alpha = 0$ are,

$$\Omega_f = I_f L_f \qquad (42)$$

$$\Omega_a = I_f M_0 \qquad (43)$$

$$\Omega_b = 0 \qquad (44)$$

The flux linkages at any other field position are,

$$\Omega_f = i_f L_f + i_a M_{fa} + i_b M_{fb} \qquad (45)$$

$$\Omega_a = i_a L_a + i_f M_{af} \qquad (46)$$

$$\Omega_b = i_b L_b + i_f M_{bf} \qquad (47)$$

since $M_{ab} = 0$ as for the previous two-phase case considered.

Equating (42) and (45), (43) and (46), (44) and (47), solving simultaneously and substituting (9) (12) (13) and (22),

$$i_f = I_f \frac{1 - K^2 \cos\alpha}{1 - K^2} \qquad (48)$$

$$i_a = I_f \frac{M_0}{L_a} \frac{(1 - 0.5\,K^2) - \cos\alpha + 0.5\,K^2 \cos 2\alpha}{1 - K^2} \qquad (49)$$

$$i_b = -I_f \frac{M_0}{L_a} \frac{\sin\alpha - 0.5\,K^2 \sin 2\alpha}{1 - K^2} \qquad (50)$$

These currents are plotted in Fig. 6 for $K = 0.85$ and

$$\frac{M_0}{L_a} = 0.85.$$

(b) Three-phase alternator, (Case 7, Fig. 1).

There are three circuits, the field circuit, phase a and phase b. Maximum current is obtained in phase a if the short-circuit occurs at $\alpha = 30$ deg. since at this armature position there is no field flux enclosed by phase b. The flux linkages of the three circuits at $\alpha = 30$ deg. are

$$\Omega_f = I_f L_f \tag{51}$$

$$\Omega_a = 0.5 \sqrt{3}\, I_f M_0 \tag{52}$$

$$\Omega_b = 0 \tag{53}$$

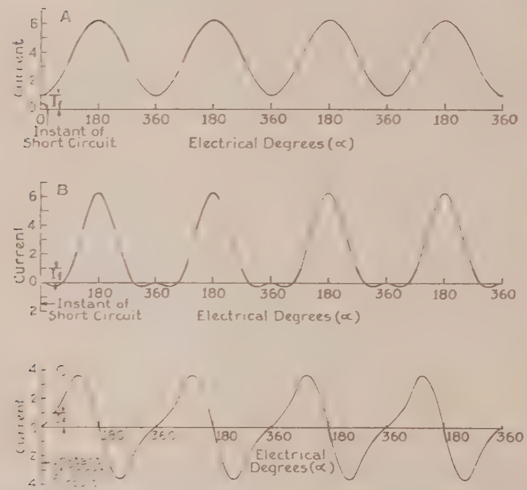

FIG. 6—INITIAL SHORT-CIRCUIT CURRENTS; CASE 6

Curve A—Field current. Eq. (48)
Curve B—Current in phase a. Eq. (49)
Curve C—Current in phase b. Eq. (50)

The flux linkages for any value of α are,

$$\Omega_f = i_f L_f + i_a M_{fa} + i_b M_{fb} \tag{54}$$

$$\Omega_a = i_a L_a + i_f M_{af} + i_b M_{ab} \tag{55}$$

$$\Omega_b = i_b L_b + i_f M_{bf} + i_a M_{ba} \tag{56}$$

Equating (51) and (54), (52) and (55), (53) and (56), solving simultaneously and substituting (9), (12), (22), (25), and (35)

$$i_f = I_f \frac{1 - K^2 \cos(\alpha - 30)}{1 - K^2} \tag{57}$$

$$i_a = \frac{2}{\sqrt{3}} I_f \frac{M_o}{L_a}$$

$$\frac{(1-0.5\, K^2) - \cos(\alpha-30) + 0.5\, K^2 \cos 2(\alpha-30)}{1 - K^2} \tag{58}$$

$$i_b = \frac{2}{\sqrt{3}} I_f \frac{M_0}{L_a}$$

$$\frac{0.5\,(1-0.5\, K^2) - \sin \alpha - 0.5\, K^2 \cos 2(\alpha+30)}{1 - K^2} \tag{59}$$

These currents are plotted in Fig. 7 for $K = 0.85$ and

$$\frac{M_0}{L_a} = 0.85.$$

3. Three-Phase Short-Circuit

(a) Three-phase alternator, (Case 8, Fig. 1).

There are four circuits to consider; the field circuit, phase a, phase b and phase c. The flux linkages of these circuits at $\alpha = 0$ are,

$$\Omega_f = I_f L_f \tag{60}$$

$$\Omega_a = I_f M_0 \tag{61}$$

$$\Omega_b = -\, 0.5\, I_f M_0 \tag{62}$$

$$\Omega_c = -\, 0.5\, I_f M_o \tag{63}$$

The flux linkages at any value of α are,

$$\Omega_f = i_f L_f + i_a M_{fa} + i_b M_{fb} + i_c M_{fc} \tag{64}$$

$$\Omega_a = i_a L_a + i_f M_{af} + i_b M_{ab} + i_c M_{ac} \tag{65}$$

$$\Omega_b = i_b L_b + i_f M_{af} + i_a M_{ba} + i_c M_{bc} \tag{66}$$

$$\Omega_c = i_c L_c + i_f M_{cf} + i_a M_{ca} + i_b M_{cb} \tag{67}$$

Equating (60) and (64), (61) and (65), (62) and (66), and (63) and (67), solving simultanelusly and substi-

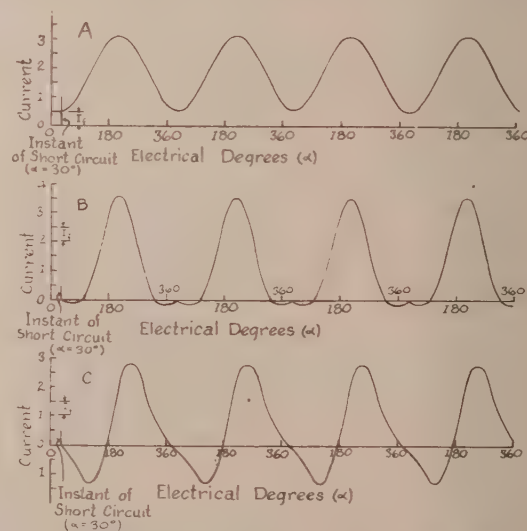

FIG 7—INITIAL SHORT-CIRCUIT CURRENTS; CASE 7

Curve A—Field current. Eq. (57)
Curve B—Current in phase a. Eq. (58)
Curve C—Current in phase b. Eq. (59)

tuting (9), (12), (13), (22), (35), and the three relations

$$L_a = L_c \tag{68}$$

$$M_{ac} = -\, 0.5\, L_a \tag{69}$$

$$M_{cf} = M_0 \cos(\alpha + 120) \tag{70}$$

$$i_f = I_f \frac{1 - K^2 \cos \alpha}{1 - K^2} \tag{71}$$

$$i_a = \frac{2}{3} I_f \frac{M_0}{L_a} \frac{(1-0.5\, K^2) - \cos \alpha + 0.5\, K^2 \cos 2\,\alpha}{1 - K^2} \tag{72}$$

$$i_b = -\frac{1}{3} I_f \frac{M_0}{L_a}$$

$$\frac{(1-0.5\,K^2)+2\cos(\alpha-120)-K^2\cos 2\,(\alpha+120)}{1-K^2} \quad (73)$$

$$i_c = -\frac{1}{3} I_f \frac{M_0}{L_a}$$

$$\frac{(1-0.5\,K^2)+2\cos(\alpha+120)-K^2\cos 2\,(\alpha-120)}{1-K^2} \quad (74)$$

These equations are plotted in Fig. 8 for $K = 0.85$, and

$$\frac{M_0}{L_a} = 0.85.$$

(b) Three-phase alternator (Case 9, Fig. 1)

The current equations obtained for a three-phase

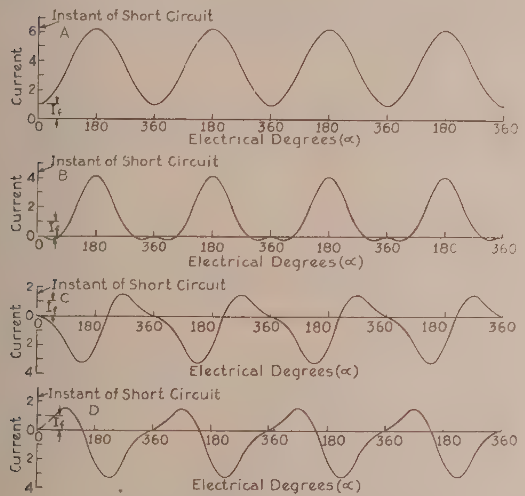

FIG. 8—INITIAL SHORT-CIRCUIT CURRENTS; CASES 8 AND 9

Curve A—Field current. Eq. (71)
Curve B—Current in phase a. Eq. (72)
Curve C—Current in phase b. Eq. (73)
Curve D—Current in phase c. Eq. (74)

short-circuit terminal-to-terminal are the same as those for a three-phase short-circuit terminal-to-neutral.

PERMANENT CONDITION

In the permanent condition, the algebraic sum of the flux linkages in each armature circuit must be zero since the flux linkages originally caught in these circuits have been dissipated during the transient period between the initial and permanent states. The flux linkages of the field circuit will be equal to those supplied by the exciter.

1. Single-Phase Short Circuit.

(a) Single-phase or polyphase alternator.

As in the corresponding case for the initial short-circuit condition a general formula can be obtained for the single-phase short-circuit current of a single-phase, two-phase, or three-phase alternator, when only one armature phase is involved in the short circuit (Cases 1 to 3, Fig. 1.) The flux linkages of the two circuits involved, are,

$$i_f\,L_f + i_a\,M_{fa} = I_f'\,L_f \quad (75)$$

$$i_a\,L_a + i_f\,M_{af} = 0 \quad (76)$$

where I_f' is that constant value of field current that would be required on open circuit to produce the same number of flux linkages with the field circuit as exist under the permanent short circuit condition.

Solving these two equations simultaneously and substituting (9) and (12)

$$i_f = I_f' \frac{1}{(1-0.5\,K^2) - 0.5\,K^2\cos 2\,\alpha} \quad (77)$$

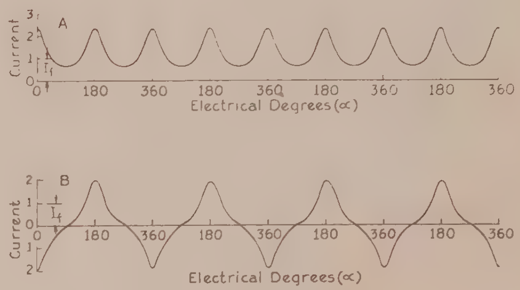

FIG. 9—PERMANENT SHORT-CIRCUIT CURRENTS; CASES 1, 2 AND 3

Curve A—Field current. Eq. (80)
Curve B—Current in phase a. Eq. (81)

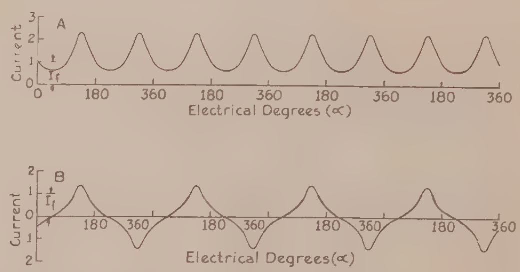

FIG. 10—PERMANENT SHORT-CIRCUIT CURRENTS; CASE 4

Curve A—Field Current. Eq. (86)
Current B—Current in circuit $a\,b$. Eq. (87)

$$i_a = -I_f' \frac{\cos\alpha}{(1-0.5\,K^2) - 0.5\,K^2\cos 2\,\alpha} \quad (78)$$

The direct component of the field current (77) is due to the flux linkages supplied by the exciter and is, therefore, equal to the field current I_f which flowed before short-circuit. This direct component is found by integrating (77) between proper limits and dividing by the abscissa. Thus,

$$I_f = \frac{2}{\pi}\int_0^{\frac{\pi}{2}} \frac{I_f'}{(1-0.5\,K^2) - 0.5\,K^2\cos 2\,\alpha}\,d\,\alpha$$

$$= \frac{I_f'}{\sqrt{1-K^2}}$$

or

$$I_f' = I_f \sqrt{1 - K^2} \qquad (79)$$

Substituting (**79**) in (**77**) and (**78**),

$$i_f = I_f \frac{\sqrt{1 - K^2}}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2\,\alpha} \qquad (80)$$

$$i_a = -\,I_f \frac{M_0}{L_a} \frac{\sqrt{1 - K^2}\cos\alpha}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2\,\alpha} \qquad (81)$$

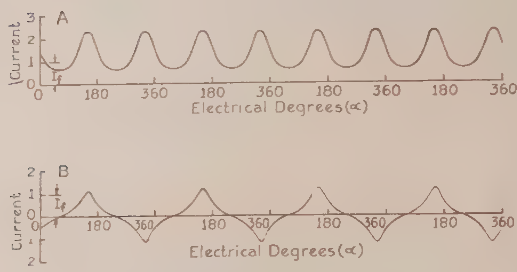

FIG. 11—PERMANENT SHORT-CIRCUIT CURRENTS; CASE 5

Curve *A*—Field current. Eq. (**92**)
Curve *B*—Current in circuit *a b*. Eq. (**93**)

These currents are plotted in Fig. 9 for $K = 0.85$ and

$$\frac{M_0}{L_a} = 0.85.$$

(b) Two-phase alternator, single-phase terminal-to-neutral short-circuit (Case 4, Fig. 1).

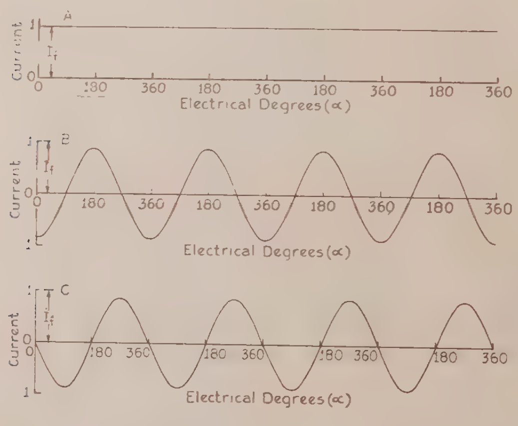

FIG. 12—PERMANENT SHORT-CIRCUIT CURRENTS; CASE 6

Curve *A*—Field current. Eq. (**101**)
Curve *B*—Current in phase *a*. Eq. (**102**)
Curve *C*—Current in phase *b*. Eq. (**103**)

The flux linkages of the two circuits involved are: [See (**19**) and (**20**)].

$$i_f L_f + i_{ab} (M_{fa} - M_{fb}) = I_f' L_f \qquad (82)$$

$$i_f (M_{af} - M_{bf}) + i_{ab} (L_a + L_b) = 0 \qquad (83)$$

Solving simultaneously and substituting (**9**), (**12**), (**13**) and (**22**).

$$i_f = I_f' \frac{1}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2\,(\alpha + 45)} \qquad (84)$$

$$i_{ab} = -\frac{1}{\sqrt{2}} I_f' \frac{\cos(\alpha + 45)}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2(\alpha + 45)} \qquad (85)$$

Since (**84**) is of the same form as (**77**) the value of I_f' for this case will be the same as that given by (**79**). Substituting (**79**) in (**84**) and (**85**),

$$i_f = I_f \frac{\sqrt{1 - K^2}}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2\,(\alpha + 45)} \qquad (86)$$

$$i_{ab} = -\frac{1}{\sqrt{2}} I_f \frac{M_0}{L_a} \frac{\sqrt{1 - K^2}\cos(\alpha + 45)}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2\,(\alpha + 45)} \qquad (87)$$

These currents are plotted in Fig. 10 for K and $\frac{M_0}{L_a}$ equal to 0.85.

(c) Three-phase alternator, single-phase terminal-to-terminal short-circuit (Case 5, Fig. 1).

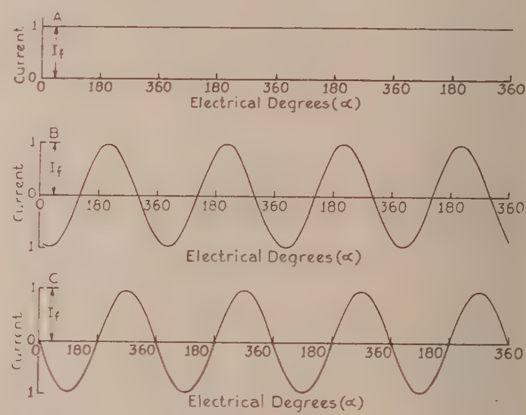

FIG. 13—PERMANENT SHORT-CIRCUIT CURRENTS; CASE 7

Curve *A*—Field current. Eq. (**110**)
Curve *B*—Current in phase *a*. Eq. (**111**)
Curve *C*—Current in phase *b*. Eq. (**112**)

The linkages of the circuits involved are from (**36**) and (**37**),

$$i_f L_f + i_{ab} (M_{fa} - M_{fb}) = I_f' L_f \qquad (88)$$

$$i_f (M_{af} - M_{bf}) + i_{ab}\, 3\, L_a = 0 \qquad (89)$$

Solving simultaneously and substituting (**9**), (**12**) and (**25**),

$$i_f = I_f' \frac{1}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2\,(\alpha + 30)} \qquad (90)$$

$$i_{ab} = -\frac{1}{\sqrt{3}} I_f' \frac{M_0}{L_a} \frac{\cos(\alpha + 30)}{(1 - 0.5\,K^2) - 0.5\,K^2 \cos 2\,(\alpha + 30)} \qquad (91)$$

Equation (**93**) is again of the same form as (**77**) so

that I_f' is given by (**79**). Substituting for I_f' in (**90**) and (**91**);

$$i_f = I_f \frac{\sqrt{1 - K^2}}{(1 - 0.5\, K^2) - 0.5\, K^2 \cos 2\,(\alpha + 30)} \tag{92}$$

$$i_{ab} = -\frac{1}{\sqrt{3}} I_f \frac{M_0}{L_a}$$

$$\frac{\sqrt{1 - K^2}\cos(\alpha + 30)}{(1 - 0.5\, K^2) - 0.5\, K^2 \cos 2\,(\alpha + 30)} \tag{93}$$

These equations are plotted in Fig. 11 for K and

$$\frac{M_0}{L_a} = 0.85.$$

2. Two-Phase Short Circuit.

(a) Two-phase alternator, (Case 6, Fig. 1).

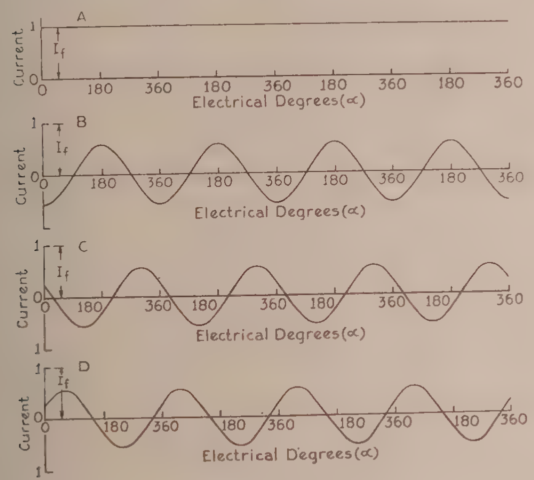

FIG. 14—PERMANENT SHORT-CIRCUIT CURRENTS; CASES 8 AND 9

Curve A—Field current. Eq. (**117**)
Curve B—Current in phase a. Eq. (**118**)
Curve C—Current in phase b. Eq. (**119**)
Curve D-Current in Phase c. Eq. (**120**)

The flux linkages of the circuits involved, from (**45**), (**46**) and (**47**) are,

$$i_f L_f + i_a M_{fa} + i_b M_{fb} = I_f' L_f \tag{94}$$
$$i_a L_a + i_f M_{af} = 0 \tag{95}$$
$$i_b L_b + i_f M_{bf} = 0 \tag{96}$$

Solving simultaneously and substituting (**9**), (**12**), (**13**), and (**22**),

$$i_f = I_f' \frac{1}{1 - K^2} \tag{97}$$

$$i_a = -I_f' \frac{M_0}{L_a}\frac{\cos\alpha}{1 - K^2} \tag{98}$$

$$i_b = -I_f' \frac{M_0}{L_a}\frac{\sin\alpha}{1 - K^2} \tag{99}$$

The field current (**97**) has only a direct component, and is therefore equal to I_f.

Hence,

$$I_f' = I_f\,(1 - K^2) \tag{100}$$

Substituting (**100**) in (**97**), (**98**) and (**99**),

$$i_f = I_f \tag{101}$$

$$i_a = -I_f \frac{M_0}{L_a}\cos\alpha \tag{102}$$

$$i_b = -I_f \frac{M_0}{L_a}\sin\alpha \tag{103}$$

These currents are plotted in Fig. 12 for K and

$$\frac{M_0}{L_a} \text{ equal to } 0.85.$$

(b) Three-phase alternator, (Case 7, Fig. 1).

The flux linkages of the circuits involved are from (**54**), (**55**) and (**56**),

$$i_f L_f + i_a M_{fa} + i_b M_{fb} = I_f' L_f \tag{104}$$
$$i_a L_a + i_f M_{af} + i_b M_{ab} = 0 \tag{105}$$
$$i_b L_b + i_f M_{bf} + i_a M_{ba} = 0 \tag{106}$$

Solving simultaneously and substituting (**9**), (**12**), (**22**), (**25**) and (**35**),

$$i_f = I_f' \frac{1}{1 - K^2} \tag{107}$$

$$i_a = -\frac{2}{\sqrt{3}} I_f' \frac{M_0}{L_a}\frac{\cos(\alpha - 30)}{1 - K^2} \tag{108}$$

$$i_b = -\frac{2}{\sqrt{3}} I_f' \frac{M_0}{L_a}\frac{\sin\alpha}{1 - K^2} \tag{109}$$

The field current (**107**) is the same as (**94**) so that the value of I_f' is given by (**100**). Substituting for I_f';

$$i_f = I_f \tag{110}$$

$$i_a = -\frac{2}{\sqrt{3}} I_f \frac{M_0}{L_a}\cos(\alpha - 30) \tag{111}$$

$$i_b = -\frac{2}{\sqrt{3}} I_f \frac{M_0}{L_a}\sin\alpha \tag{112}$$

These equations are plotted in Fig. 13 for $K = 0.85$ and

$$\frac{M_0}{L_a} = 0.85.$$

3. Three-Phase Short Circuit.

(a) Three-phase alternator, (Case 8, Fig. 1).

The flux linkage equations of the four circuits involved are,

$$i_f L_f + i_a M_{fa} + i_b M_{fb} + i_c M_{fc} = I_f' L_f \tag{113}$$
$$i_a L_a + i_f M_{af} + i_b M_{ab} + i_c M_{ac} = 0 \tag{114}$$
$$i_b L_b + i_f M_{bf} + i_a M_{ba} + i_c M_{bc} = 0 \tag{115}$$
$$i_c L_c + i_f M_{cf} + i_a M_{ca} + i_b M_{cb} = 0 \tag{116}$$

Solving simultaneously and substituting (**9**), (**12**), (**22**), (**25**), (**35**), (**68**), (**69**) and (**70**), and the value of I_f' given by (**100**) since i_f comes out the same as (**97**),

$$i_f = I_f \tag{117}$$

$$i_a = -\frac{2}{3} I_f \frac{M_0}{L_a} \cos \alpha \quad (118)$$

$$i_b = -\frac{2}{3} I_f \frac{M_0}{L_a} \cos (\alpha - 120) \quad (119)$$

$$i_c = -\frac{2}{3} I_f \frac{M_0}{L_a} \cos (\alpha + 120) \quad (120)$$

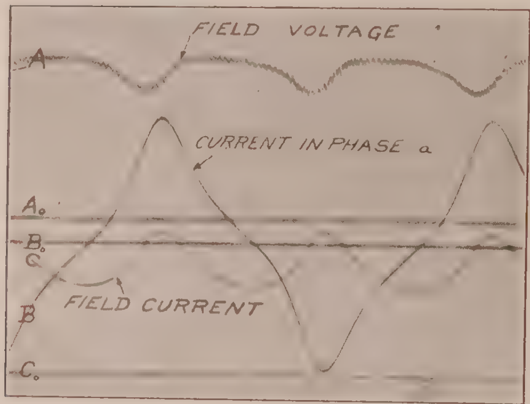

Fig. 15—Oscillogram of the Permanent Single-Phase Short-Circuit Currents of a Three-Phase Alternator Short-Circuited Between Two Terminals

These currents are plotted in Fig. 14 for $K = 0.85$ and

$$\frac{M_0}{L_a} = 0.85.$$

(b) Three-phase alternator, (Case 9, Fig. 1).

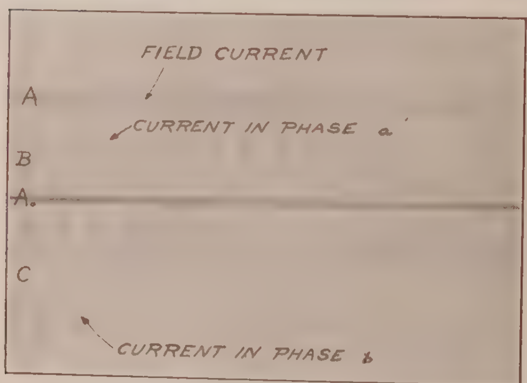

Fig. 16—Oscillogram of the Permanent Two-Phase Short-Circuit Currents of a Three-Phase Alternator Short-Circuited Between Two Terminals and Neutral

The two armature currents are of different calibration.

The current equations for this case are the same as those for a three-phase short-circuit terminal-to-neutral.

NOTATION

α electrical angle of rotation of field. (See Fig. 2).

I_f value of field current in amperes before short-circuit.

I_f' the constant value of field current in amperes under the permanent short-circuit condition that would be required on open circuit to produce the same number of flux linkages with the field circuit as exist under the permanent short-circuit condition.

i_a, i_b, i_c instantaneous values of current in amperes in phases a, b and c respectively.

i_{ab} instantaneous values of current in amperes in the single-phase circuit composed of phases a and b in series.

i_f instantaneous value of field current in amperes.

K coefficient of magnetic coupling between any one armature phase and the field circuit. (See Eq. **12**).

L_a, L_b, L_c true coefficient of self inductance in henrys of phases a, b and c respectively.

L_f true coefficient of self inductance in henrys of field current.

$M_{ab}, = M_{ba}, M_{ac} = M_{ca}, M_{bc} = M_{cb}$ coefficient of mutual inductance in henrys between phases a and b, a and c, and b and c.

$M_{fa}, = M_{af}, M_{fb} = M_{bf}, M_{fc} = M_{cf}$ coefficient of mutual inductance in henrys between the field circuit f and phases a, b and c respectively for any value of α

M_{fab} coefficient of mutual inductance in henrys between the field circuit and phases a and b in series for any value of α

M_0 coefficient of mutual inductance in henrys between the field circuit and any one armature phase when in the position of maximum coupling.

$\Omega_a, \Omega_b, \Omega_c$ flux linkages of phases a, b and c respectively for any value of α

Ω_{ab} flux linkages of the single phase circuit composed of phases a and b in series for any value of α

Ω_f flux linkages of the field circuit for any value of α

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Electric Shovels

BY D. J. SHELTON[1] AND D. STOETZEL[2]
Non-Member Associate, A. I. E. E.

Synopsis.—*The use of electric drive on power shovels has been increasing very rapidly during the past few years, especially in open-pit coal and iron mines. Probably no class of industrial equipment has been the subject of such radical changes in design in the past two or three years. For this reason, more than any other, it is probable that the ultimate users, in general, are less familiar with the highly developed electrical apparatus available for their purposes than is the case in any other branch of industry. On account of the unusual conditions encountered, the electrical equipment must be of a very special nature. This article shows the reasons for the large increase in this business, discusses the special requirements of the service, and explains the characteristics and advantages of the various types of equipment available.*

* * * * *

THE attitude of owners and operators toward the electric shovel has been passing through a transition very similar to that which is part of the history of the modern mine hoists. Heretofore the electric shovel was installed more or less as an experiment, principally because many arguments had been advanced in its favor on paper. The indications now, however, are that the day is not far distant when the purchaser of a power shovel will regard the electric machine as the standard and logical application, instead of feeling that it is necessary to collect and weigh a great mass of favorable evidence in order to justify the electric drive. Every new installation strengthens this attitude and there is no record of any electric shovel being replaced by a steam machine as a result of poor performance. Ninety per cent of our large mine hoists are now built with electric drive and there is no reason why the situation with regard to shovels should not be the same very soon. The rapid progress toward this end is shown in Fig. 1.

In view of this, it is natural that the power shovel should be of continually increasing interest to those connected with the electrical industry, particularly to the engineer with regard to the special nature of its application.

The electric shovel always has, and probably always will, carry a higher initial cost than the steam machine. However, the higher first cost can practically always be justified when operating expense, maintenance, and output are considered. The reason for the comparatively high price of the electric shovel is due to several factors: In the first place the number of mechanical parts is increased by the larger gear ratios between motor and shovel motions. Roughly speaking, the speed of electric motors applied is about twice that of the steam engines they replace. Electric drive also requires a stronger shovel mechanically as there is a range of adjustment possible in the electrical apparatus which, while not recommended for use, permits greater torque and pull than are possible with steam drive. As a matter of fact, electric drive has, in a certain sense, resulted in the improvement and strengthening of the standard shovel models. Another factor in the price of electric machines is the cost of the electrical equipment itself. This is necessarily much higher than for a corresponding amount of steam equipment. Most of the apparatus is of a special nature, either as regards electrical characteristics or mechanical construction, and is not built in such quantities that production savings result. This applies particularly to the larger and more expensive shovel models, although the general design is becoming stabilized.

It is recognized and admitted that the modern steam shovel is a highly developed machine and one which has

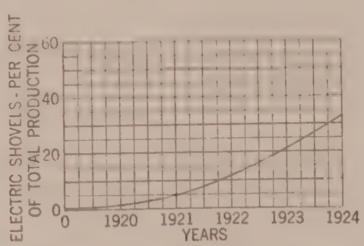

FIG. 1—CURVE SHOWING INCREASE IN APPLICATION OF ELECTRIC DRIVE TO POWER SHOVELS

operating characteristics of speed and torque well suited to the work in hand. The electrical equipment for shovels has been designed with this in mind and, with the voltage-control type, equipments are being built to equal, or even exceed if necessary, the performance characteristics of the most modern steam machines. Fig. 2 shows the bail speed—bail pull characteristics of various types of machines.

The great advantages of the electric shovel are reliability and economy, and these are directly related to low maintenance and operating costs. The greater reliability of the electric as compared with the steam machine, is due partly to the substitution of the rotary motion of the motors for the reciprocating motion of the steam engines. The electric shovel is cleaner, more orderly and, in general, better maintained than the steam machine. The electric supply, brought to the shovel through a flexible cable, is more dependable and

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subject to fewer shut-downs than the water and coal supply to the steamer. This is especially true in winter operation, when frozen water pipes are common and transportation difficult. It is not easy to get good comparative operating records, but experienced operators who are familiar with both types of machines are almost unanimous in the opinion that the percentage of working time is much greater for the electric than for the steam machine.

The question of operating economy is easier to consider in detail. Coal, delivered at the shovel, is usually expensive and its conversion into mechanical energy with the limited boiler equipment and reciprocating engines of the steamer is a very inefficient process. On the other hand, the central station gets its fuel at the

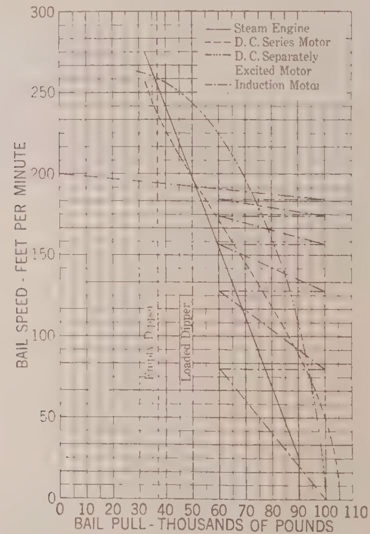

FIG. 2—CURVES SHOWING CHARACTERISTICS OF SHOVELS EQUIPPED WITH VARIOUS KINDS OF MOTORS

best possible rate. Furthermore, the turbine-generator is a highly developed and efficient producer and, even though the energy applied to the shafts on the electric machine has had to undergo several more steps of conversion from one form to another and has been transmitted over a considerable distance, much more actual working energy is obtained from a pound of coal than it is possible to get on the steam machine.

A large saving with the electric shovel is due to the fact that a smaller crew is required, two instead of three men being necessary by the elimination of the fireman. The pit-gang can also be reduced by one or two men because there is no water and coal supply to be maintained. Furthermore, no watchman is required to keep the fires over night. The steam shovel is also always at the mercy of water supply in the locality in which it operates, and the water available is frequently very unfit for boiler use.

With the majority of operators, output or yardage is the first consideration, and all other factors in operation are subordinated to this. Continuity of service is the all-convincing argument for the electric shovel. Assured of freedom from shut-downs for overhauling, adjustments or repairs, this type of shovel produces surprising records, especially for operation over a long period of time.

Records show that, considering an average, the repairs on electric machines are approximately 18 per cent less than those on steam machines.

There seems to be no question but that the electric shovel is cheaper to maintain and operates a larger percentage of the time than the steam machine. Of course there are individual cases where the maintenance of electric shovels runs high and the percentage of time operating runs low, due either to inefficient operation or local conditions which cannot be controlled.

In this connection, it is interesting to note that several large shovel operators and many small ones have recently decided on a complete change-over from steam to electric drive, as the result of very careful study involving, in some cases, actual tests over a long period of operation with both types of equipment.

It is very difficult to obtain records of operating data on electric and steam shovels that will be comparable and conclusive. The collection of such evidence is made more difficult by the reluctance of many operators to discuss confidential data in regard to their operating costs. We are fortunate, however, in being able to present the unbiased opinions of some large operators who have had extensive opportunity to prove for themselves the superiority of the electric machine.

Mr. R. S. Walker, Consulting Engineer of the M. A. Hanna Company, Cleveland, Ohio, has expressed himself as follows in an article describing the first complete electrification of an open-pit, iron-ore mine in Minnesota:

"SAVINGS EFFECTED BY ELECTRIC SHOVEL (350-TON CLASS) IN COMPARISON WITH STEAM MACHINE

Labor. The electric shovel has eliminated firemen and craners, and the expense of handling coal as well as the installation and maintenance of water lines. (Electric shovels can be used in places where it would be practically impossible to supply coal to a steam machine.)

Power Cost. The power cost has averaged approximately one-half cent per cu. yd. as compared with two and one-half cents per cu. yd. fuel cost for the steam machines.

Repairs and Maintenance. Records kept over a period of four years show an average of less than $5000 per year for the 350-ton electric machines, as compared with about $25,000 per year for the steam. These figures are based on a directly comparable yardage. Delays directly chargeable to electric equipment have been less than one per cent of the available working time.

Capacity. Experience has shown that the large, full

revolving electric shovel has a capacity equal to that of the fastest steam machines. Daily runs of 8000 cu. yd. in 20 hours have been recorded, and monthly averages of 150,000 cu. yd. Over long periods, the electric machine will show greater capacity than the steam on account of a higher percentage of actual working time due to fewer breakdowns and no delays for boiler washing and repairs."

Another prominent engineer connected with one of the large mining companies has given us the following statement:

"We have found the electric maintenance on shovels to be so small as to be nearly negligible. We have also found the maintenance on gearing to be practically negligible. We believe that the maintenance of electric shovels compared with steam shovels, working under similar conditions over a similar length of time, would probably be not over one-half to two-thirds of

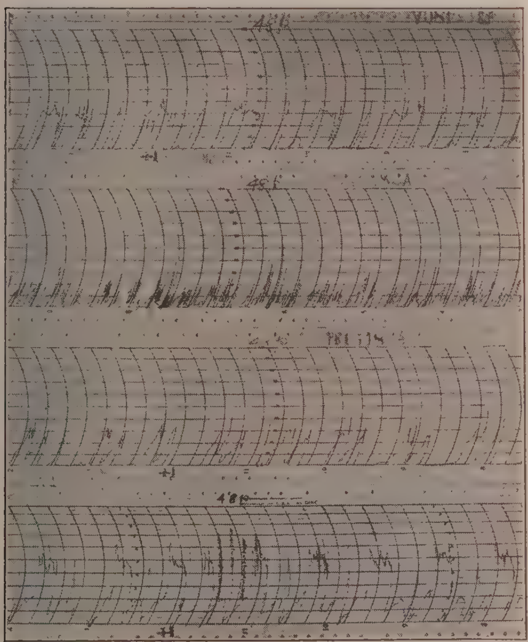

Fig. 3—Recording Meter Charts Showing Shovel Duty Cycles

Curve No. 1 Hoist-Motor Input Current, Full Scale Equals 3000 Amperes.
Curve No. 2 Crowd Motor Input Current, Full Scale Equals 1000 Amperes.
(Interval between Curved Lines, 15 seconds.)
Curve No. 3 Swing Motor Input Current, Full Scale Equals 1000 Amperes.
Curve No. 4 Kilowatt Input to Shovel; Full Scale Equals 600 kw.

the maintenance on the steam shovels. The largest saving to be obtained from the electric shovel is primarily in the cost of electric power over coal, the reduction in labor, and its availability for operation a greater portion of the time.

"All new shovels that we are now buying for our mines and quarries, where we have electric power available, will be electric shovels. We have now in operation two 300-ton revolving electric shovels, four 110-ton railroad type electric shovels and three 70-ton revolving electric shovels."

Leaving the comparison of electric and steam machines with the advantages of increased output and lower cost of operation in favor of the electric machine,

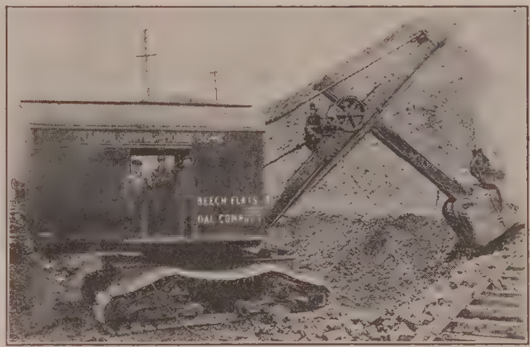

Fig. 4—Friction-Driven Electric Shovel

the various types of electrical equipment available for shovel drive may be considered.

In considering electric equipment for shovels there are two things to be kept constantly in mind. The first refers to practically all applications of electric motors; namely, the suitability of the speed, torque and operating characteristics of the electrical equipment to the work in hand. The other is the ability of the equipment to withstand vibration, rough usage and unusual conditions with the minimum of maintenance. The severity of the conditions under which shovel equipment operates is almost without parallel in industrial applications. Perhaps the nearest approach to it is found on auxiliary drives for steel mills, although here there is less vibration and better maintenance.

Shovel operations are very rapid, running as high as 20 to 30 operations per min. on the crowd motion of a small shovel. The torque will be the maximum obtainable on a large percentage of the operations, and the duty cycle is of a varied and uncertain character as shown in Fig. 3. The ideal equipment is one in which the retarding torque is constant for any controller setting and where its value is always under the control of the operator.

The vibration conditions are best appreciated when actually experienced. There is a severe pitching and rolling motion due to the action of the dipper against the bank. This is the same effect as is found on high speed trolleys but greatly intensified. There is also a secondary or constant vibration due to the action of the various gears and other fast moving parts. This undoubtedly causes more damage than the intermittent vibration due to the tendency to synchronize with certain natural vibration periods of the part subject to damage.

The majority of electric shovels are operated without

adequate electrical maintenance. Although the shovel operator gets to be more or less of a mechanical expert, the electrical equipment is rarely thoroughly understood and, if attended to at all, is as likely to be damaged as helped. Occasional inspection by an electrician is the best that can be hoped for, and regular inspection, adjustment, and renewal of working parts should not be figured on. The usual procedure is to operate until something breaks and then repair it in the quickest way possible.

While it is impossible to secure all the advantages of the full voltage control type of equipment on a single generator equipment, it has been found of great advantage on small shovels to use a type of generator having a decided drooping volt-ampere characteristic with no load voltage higher than normal, and voltage at maximum load as low as possible. This amplifies the desirable characteristics of the series motors, produces a faster shovel and, at the same time, tends to reduce the power peaks and the strains and stresses on the mechanical parts. In this connection, it is worthy of note that there have been several cases where operators, having shovels operating on a constant voltage, direct-current system, have decided on the use of a d-c./d-c. motor-generator. This decision was made after seeing the performance of similar shovels but equipped with motor-generators having drooping characteristics. In other words, even though direct current is available at the shovel, it is advisable to interpose a motor-generator on account of the superior operating characteristics produced by the drooping generator characteristic.

Fig. 5—Small Revolving Electric Shovel with Individual Motor Drive

On the earlier railroad type and the larger revolving shovels (Figs. 6 and 7) the equipment was similar to that of small shovels except that, on account of the larger sizes of the motors and because of the additional space available for the remainder of the equipment, contactor control was used. This type of control, though having done excellent work in the early days, has been practically superseded by the voltage-control type of equipment using individual generators with special characteristics for each motion. In its latest form this equipment uses separately excited motors, thereby entirely eliminating all contactors and relays. Of course no such development is possible with the a-c. type of equipment. In the appendix will be found typical lists of equipment for both railroad and large revolving types of shovels.

The question of using a-c. or d-c. motors for shovel drive has always received serious consideration. As is often the case, the superior characteristics of the one type of equipment are offset, to some extent, by the lower first cost of the other although, when proper a-c. equipment is installed and transformers mounted on the shovel, there is practically no difference in first cost. The first electric shovels were driven by a-c. motors, but the d-c. type soon came into the field with such success that, at the present time, more than 90 per cent of the installations are of that type.

Fig. 6—3¼-Yd.—Railroad Type Electric Shovel

The d-c. series motors, or the separately excited motors operating from generators with suitable characteristics, have inherent variable speed torque characteristics which produce a flexibility and speed of operation which assures large production and efficient operation under all conditions of digging. The desirable operating characteristics of the steam machine, which are imitated to a certain extent, are stalling under heavy overloads and running at speeds higher than normal under light loads. This is illustrated by the curves of Fig. 2. These characteristics make an equipment that is easily handled and controlled. Motors tend to vary their speed automatically to meet the digging condi-

Fig. 7—Large Revolving Electric Shovel

tions. With voltage-control type of equipment it is possible to get creeping speeds for inspection, oiling of moving parts, (such as the hoist chain), and close work,—all of which are impossible with any rheostatic type of control.

The use of a motor-generator between the line and the driving motors gives a buffer action which is very useful in protecting the mechanical parts against undue stresses and strains, and the line against high current peaks. Operators frequently comment on the "rubber"

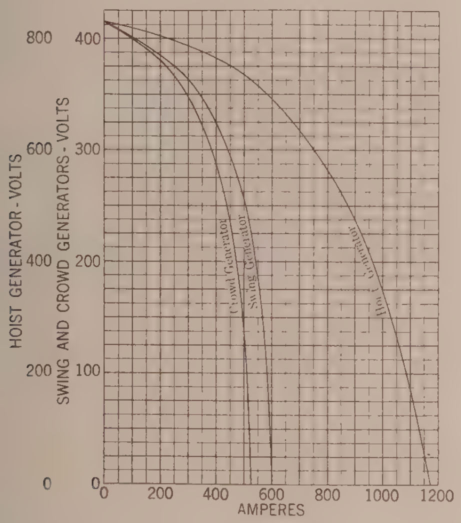

FIG. 8—SHOVEL GENERATOR CHARACTERISTIC CURVES

or "give" in the d-c. voltage-control equipment. It is practically impossible to get this with the induction motor type of equipment.

The advantages of the d-c. equipment as regards power supply are quite marked provided the shovel is kept busy. The average efficiency is considerably higher than that of a system requiring repeated periods of rheostatic losses which become greater with harder digging. Due to the generator characteristics producing low voltage at high current and high voltage at light load, the power peaks will be much lower than is possible for a constant voltage system producing the same maximum torques. The induction motor drive produces greater power peaks for the same maximum torque than those with the d-c. motors operating on a variable voltage system. Due to the higher peaks and heavier average power demand, the a-c. installation requires larger transmission lines than the d-c. This is especially true when there are only one or two shovels in a mine or quarry. In the case of remote installations, and, in fact, in almost all cases, there will be times when the a-c. voltage falls below its normal value. In these instances the performance of the d-c. equipment will not be appreciably affected while the performance of the a-c. equipment will suffer greatly due to the loss in starting and running torques.

D-c. motors, especially designed for shovel and similar service, have a considerably lower $W R^2$ than it would be possible to obtain in induction motors suitable for this class of work. Low $W R^2$ is necessary for fast operation except at the sacrifice of large quantities of energy.

The d-c. equipment is in general better suited to the severe conditions of operation. The motors are of the rugged, reliable type that has been used for a great many years in the most exacting steel mill installations. The windings are simple, and large cross section copper is used. The motor-generators are of the same general construction as those used for mining work and similar applications. In addition, they have many special features of mechanical construction designed for this particular service in order to make them exceptionally compact and substantial.

Certainly, there is no comparison between the simple drum-type controller and field resistor of the voltage control equipment, and the complicated contactor control with bulky secondary regulating resistors of the a-c. equipment. On a railroad type shovel there are upwards of 150,000 automatic contact operations per ten hour shift on the a-c. equipment as contrasted to none on the d-c. equipment. Even in the case of the small shovel equipment, the d-c. drum controllers and resistors are more compact and have simpler connections. Also, on account of the smaller number of contacts, they are more easily operated, an important point

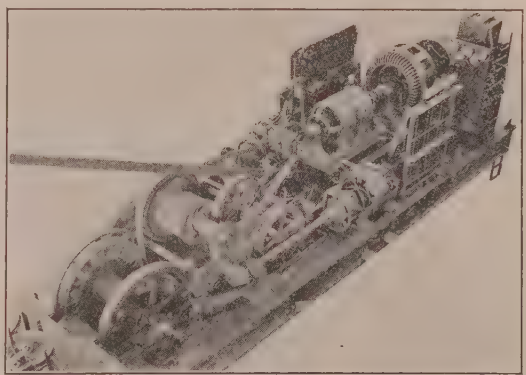

FIG. 9—RAILROAD TYPE SHOVEL WITH HOUSING REMOVED TO SHOW ARRANGEMENT OF MECHANICAL PARTS AND ELECTRICAL EQUIPMENT

when the number of motions per hour or day which the operator makes is considered.

All shovels, with the possible exception of the very largest types, are very much crowded for space. (Fig. 9). The continual endeavor is to cut down the overall dimensions of the various units comprising the equipment without sacrificing sturdiness and accessibility. On a-c. shovels the resistors and contactor equipment take up more space and require more crowding than

does the motor-generator with its three generators, on the d-c. type.

In the last analysis, however, it is operating results that count. It is extremely difficult to get real comparative data on the operation of both types. They are very seldom found on the same property and, therefore, when they are compared, one advocate will say the conditions of operation are vastly different. Fortunately, however, there are a few places where the conditions cannot be questioned. One large company operated as many as nine a-c. shovels of the larger types. They then purchased three d-c. variable-voltage shovels, and have but recently ordered six more d-c. machines. There can be but one conclusion drawn from this. The net result may be summed up as a very material reduction in the cost per ton for loading ore, coal, or spoil, or moving waste in stripping operations.

The problem of availability of power supply has heretofore been of some weight but with the tremendous recent growth in the number of central stations and suitable transmission systems, this has taken a relatively unimportant place and the majority of quarries and mines are assured of an ample and dependable supply of power at a reasonable price.

Shovel electrification is coming rapidly to the fore as indicated by the number of large operating companies making or seriously considering the change from steam to electric drive. While the foregoing indicates clearly that the authors of this paper feel that d-c., variable-voltage control is the ideal equipment at the present stage of the art, at the same time it must not be overlooked, that, under certain conditions, shovels equipped with a-c. motors have operated with a fair degree of success. With alternating current there is no necessity for motor-generators for the conversion to direct-current, although, as pointed out previously in the paper, little or no space is saved as a result, the space being taken up by the controlling panels and resistance. Sometimes the power consumption is a matter of small moment and the line can stand heavy peaks. Even then the a-c. shovel should not be considered, as the lack of control with consequent wear and tear on mechanical parts offsets any apparent advantages. The superior operating characteristics of the d-c. equipment are becoming quite generally recognized, both on the part of shovel builder and large operating companies whose engineers have had the opportunities for close first hand study of both types of equipment.

Discussion at Spring Convention

USE OF FREQUENCY CHANGERS FOR INTER-CONNECTION OF POWER SYSTEM[1]

(Woodrow)

St. Louis, Mo., April 14, 1925

R. W. Wieseman: I should like to ask Mr. Woodrow about the pull-out torque of this frequency-converter set; this is given as a little over 70,000 kw., or over twice the normal torque of the set. Is this pull-out torque the actual synchronous torque which the set can furnish for an appreciable time or is it the momentary torque of this set which includes the inertia torque of the rotors? The inertia torque is useful in a synchronous motor for a small fraction of a second only. The energy stored in the rotors of this frequency-converter set could furnish over twenty times normal load for but a few cycles. However, the limiting feature of the power output of the set is the ability of the generator to transmit power to its system. The power output of the generator, for a fraction of a second, is limited by the leakage impedance and not by the synchronous impedance because the generator magnetic flux can not change quickly and therefore it cannot be influenced by the opposing armature magnetomotive force. Thus, only two or three times normal load can be delivered by the generator for a small fraction of a second.

Therefore, to say that a frequency-converter set has a high pull-out torque without fully explaining the conditions, is misleading. The rational basis upon which synchronous machines can be compared is the constant or steady-state overload for an appreciable time, such as thirty seconds. Unity-power-factor machines of this type are usually designed with a short-circuit ration of unity and, consequently, the *true* synchronous pull-out torque is only 150 per cent of the normal torque.

Mr. Woodrow states that the synchronizing power is a function approaching the square of the voltage. In any simple circuit with constant impedance the power varies exactly as the square of the voltage. Two duplicate generators operating in parallel through a transmission line have a synchronizing power which also varies as the square of the line voltage assuming that both generators have approximately the same voltage. With a frequency-converter set operating between two systems the capacities of which are much greater than the capacity of the set, the maximum power that can be transferred varies approximately as the first power of the line voltage because, Maximum instantaneous power = (line voltage × machine virtual voltage) ÷ (transient impedance) or Maximum steady-state power = (line voltage × machine nominal voltage) ÷ (synchronous impedance). Since the virtual voltage (flux) or the nominal voltage (excitation) are constant, respectively, the maximum power varies approximately as the first power of the line voltage.

It follows that a frequency-converter set which has a steady-state maximum power of only 50 per cent above normal can carry 100 per cent overloads with a reasonable drop in line voltage for a small fraction of a second.

H. R. Woodrow: The 35,000-kv-a. frequency changer has a pull-out point of 70,000 kw. for the first few cycles covering the first oscillatory swing of surging between the systems. The sustained pull-out point is about 55,000 kw.; that is, after the magnetizing action of the motor field comes into play.

The equation for maximum instantaneous power given by Mr. Wieseman is approximately correct where the resistance of the circuits is small compared with the reactance and when his term "transient impedance" represents self inductive reactance and resistance and "machine virtual voltage," the generated voltage in the motor. The maximum steady-state power is represented by exactly the same formula, but Mr. Wieseman has used an imaginary expression, "machine nominal voltage" which represents the motor generated voltage multiplied by the

1. A. I. E. E. Journal, Vol. XLIV, April, p. 354.

ratio of another imaginary term synchronous impedance and real impedance.

Under normal operations the real impedance drop through the machine is small and therefore the voltage generated in the motor is approximately the same as the line voltage and therefore the maximum instantaneous power is equal to the line voltage squared, divided by the real impedance.

The exact expression for maximum instantaneous power between two synchronous machines having the same generated voltage is

$V^2/Z \times (1 - R/Z)$ where V = voltage, Z = impedance and R = resistance.

AUTOMATIC CONTROL FOR SUBSTATION APPARATUS[1]

(MILLAN)

ST. LOUIS, MO., APRIL 14, 1925

E. C. Stone: I want to second vigorously Mr. Millan's conclusion that the auxiliary equipment, relays, etc., which are used in automatic substations must be designed with a very great degree of reliability.

Automatic equipment adds cost to the station but we often forget that it saves operators' salaries. In any event the automatic equipment is only a small percentage of the cost of the stations and we should not hesitate to spend even 50 per cent more on it if, by doing so, we could be assured of obtaining perfect operation.

Chester Lichtenberg: One point which might be emphasized is the rapid development of automatic-station control equipment during the past three years. A survey of the situation indicates that during this period a great deal more attention has been paid to the details of design not only of the complete equipments but also of the individual devices so as to make them of maximum reliability with minimum maintenance.

For feeder-voltage regulators Mr. Millan suggests two types of protection.

1. Grounding protective relay.
2. Temperature protective relay.

Both of these devices are available and have been in automatic station service for several years. The grounding protective relay (device function No. 64) is quite well known in certain parts of the country where it has proven exceptionally valuable in giving the impulse for disconnecting apparatus from service when such apparatus developed faults to ground. The same device slightly modified last year has been successfully applied to feeder-voltage regulators and other similar devices. It will operate on any fault to ground in excess of 30 amperes and in combination with suitable oil circuit breakers affords protection against extensive damage.

Temperature protective relays (device function No. 49) for feeder-voltage regulators are available. They have not been sold in general, however, because the purchasers of the feeder-voltage regulators do not care to pay the small additional expense which these devices would add.

Most of the a-c. automatic stations which have been installed to date are of the relatively simple type described by Mr. Millan. There are outstanding examples, however, of very complete a-c. automatic stations which are very much more extensive and which have been in successful operation for three or more years. For example, the Kansas City Power & Light Company has had in operation since 1921 two a-c. automatic substations. They each have two or more incoming lines with two or more banks of transformers and a dozen or more outgoing feeders. The stations are designed so as to have only sufficient transformers connected in service to supply power to the load. Consequently, in times of light load a minimum transformer capacity is excited. The stations are also arranged so that in case of trouble to any transformer bank or incoming line the bank or line is automatically switched out of service and replaced by an emergency bank or line.

The successful operation of these automatic stations emphasizes another point. It is the requirement that relaying devices for automatic substations be considered on quite a different basis from those for manual substations. In the manual station there is an attendant. It is his ordinary duty to watch the instruments provided for him so that he may check the operation of the various relays, etc. In case of trouble he is expected to substitute himself for the relay devices should they fail. In an automatic station there is no attendant. If a relay is called upon to perform its function it must not only be ready to perform that function but must perform it successfully. If there is dust on the contacts the contacts must be so designed that when operating the dust must either be wiped off or contact be made notwithstanding the dust. If the operation is to occur at 180 volts then it must occur at 180 volts and not wait until the pressure is at some other value. This has meant a new and very rigid standard with regard to the performance of relaying devices for automatic stations and the successful operation of several thousand of these during the past ten years evidences what can be done.

In connection with automatic stations there have been developed a number of supervisory systems. Some of these use automatic telephone relays. Such relays are suited for automatic telephone-central service but are not suited for automatic power-substation service. For example, the usual automatic telephone exchange has reasonably clean rooms kept at a relatively constant temperature. Besides, the relays are usually inspected and tested about once a day or at the most once a week. In automatic station service, however, supervisory system relays are frequently called upon to operate without inspection or test excepting at intervals of one month or more. The ones in the outlaying stations are subjected to temperatures varying from 40 deg. cent. below zero to 80 deg. cent. or more above zero. The conditions, therefore, are quite different and it is easy to see why a totally different class of relaying device is required for a supervisory system in automatic power-substation service than for automatic telephone-exchange work. This analysis has been proven correct by actual experience. So much so that one of the manufacturers furnishing supervisory systems has discarded all automatic telephone relays and uses relays developed exclusively for railway train-dispatching service where inspections are made not oftener than once a year. These relays represent almost the last word in relay development because experience has indicated that when correctly installed they require no maintenance and practically no inspection.

E. K. Huntington: In our system in Rochester, New York, we have recently installed two a-c. and one Edison automatic substations. The reference that various devices, which have been taken from the manual station and applied to the automatic station, should be more reliable is certainly one that needs our attention. Among these might be mentioned bearing temperature of relays and devices which cannot be easily tested after their installation. We have found that most devices are subject to change in calibration after installation and unless tested periodically are unreliable for that reason. In one automatic station in which there is a vertical hydro-generator, we are using a recording bearing-temperature device which not only records the bearing temperature and shows that it is working, but also has contacts on it for tripping the machine in case the temperature reaches the value at which the contacts are set to operate. Such a device seems very desirable where its cost is warranted.

We have found that constant attention is necessary on all devices in automatic stations. At the present time we are making a practise of putting each automatic operation through its complete cycle at least once every month, as a check upon the operation of various devices which may stand for a considerable time without operating in actual service.

1. A. I. E. E. JOURNAL, Vol. XLIV, June, p. 588.

In our Edison system, we have about a 20,000-kw. load supplied over an area of about one mile radius. The voltage-regulating devices, which were supplied with our Edison automatic substation equipment hold bus voltage within about two volts either way, or a four-volt swing on the 250-volt system. In our particular case, this has worked out very satisfactorily and no objectionable exchange of load has been noticed. More sensitive voltage-regulating devices are undoubtedly necessary, in supplying the highly concentrated loads of the larger cities but not in the average Edison system.

H. O. Stephens (communicated after adjournment): Mr. Millan points out a number of details in the automatic equipment which may give trouble on account of failure to operate. In particular, he mentions the possibility of trouble developing with thermostats and water-control valves on water-cooled transformers. The remedy is obvious and should not be passed over without mention.

When the type of transformer for automatic sub-stations is being selected, there are usually three choices available:

First: Water-cooled transformers.

Second: Combination self-cooled, water-cooled transformers capable of carrying light loads without water, but with automatic thermostats and valves for turning on the water supply for water cooling during peak loads.

Third: Self-cooled transformers capable of carrying the maximum peak load.

The cost of a self-cooled transformer will range from zero to fifty per cent greater than the cost of a water-cooled transformer, depending upon the size, complications, and voltage; while the cost of a combination self-cooled, water-cooled transformer will be approximately midway between the cost of a water-cooled transformer and a self-cooled transformer.

Transformers of all three types have been used in automatic substations but it is my opinion that while more or less practical control devices are on the market for controlling the water for water-cooled and combination self-cooled water-cooled transformers, they involve altogether too "clever" designing. The simple self-cooled transformer capable of carrying the maximum peak load is the obvious solution as all of the auxiliary thermostats and valves for controlling the water supply are eliminated and the increase in cost of the self-cooled transformer can be justified when it is considered that the efficiency of the self-cooled transformer is also usually higher. The self-cooled transformer has another decided advantage since the oil temperature is a much better indication of the load than it is on a water-cooled transformer; while the oil temperature of combination self-cooled water-cooled transformer fluctuates so widely that it is of little or no value in indicating the load. A reliable thermostat for tripping off the load in case the transformer reaches a dangerous temperature can readily be installed in the top oil of a self-cooled transformer. These facts should be very carefully considered before deciding on the use of anything but self-cooled transformers in an *automatic* substation.

INITIAL AND SUSTAINED SHORT CIRCUITS IN SYNCHRONOUS MACHINES

(Karapetoff)

SHORT-CIRCUIT CURRENTS OF SYNCHRONOUS MACHINES

(Franklin)

St. Louis, Mo., April 14, 1925

R. E. Doherty: Progress in most investigations of the complexity of those taken up in the two papers on short-circuit currents is made step by step.

As Professor Karapetoff brought out, there are still further steps to take; saturation must be taken into account and also the effect of salient poles. But I think that the equations and the results which have been obtained by Mr. Franklin and which Professor Karapetoff's method has completely checked have formed another definite step in advance in this problem.

I wish to say a word about methods. In 1918, I was engaged in some work along these lines and I was confronted, like everybody else who has undertaken such studies, with the practically impossible undertaking of solving short-circuit problems when resistance is taken into account. In the investigation it appeared that sufficiently close approximation could be made in many instances by neglecting resistance.

I proposed, at that time, the constant-linkage theorem which Mr. Franklin has utilized in his paper. It is the simple relation which follows at once from Kirchoff's Law and the assumption of zero resistance. From these two premises, the theorem stated in Mr. Franklin's paper is this: In any closed circuit without resistance the flux linkages must remain constant. It doesn't matter how many secondary circuits there are, or what the network involves, the theorem is rigidly true.

Now, the question which I wish to raise with respect to Prof. Karapetoff's paper is that if this theorem is true (he makes the assumption that the resistance is zero), why is it necessary to go back to Kirchoff's equations in each particular case as he does, performing the integration and finding the integration constant, which in every case, of course, turns out to be the known magnetic linkages existing when the circuit was closed?

Prof. Karapetoff has stated that after making the integration, that is, dropping the derivative symbol, the problem is solved. That is exactly where you start if you apply the constant-leakage theorem. Mr. Franklin has followed the latter method. That is a point more of interest than of importance, but it is a question of ease with which the problem can be solved, if the facilities afforded by a simple theorem are taken advantage of.

R. W. Wieseman: In single-phase generators usually only two-thirds of the coils per pole are used and connected in series. This corresponds to a 120-deg. phase belt and is classified under Case 5 of Mr. Franklin's paper. From Table II we find that the initial single-phase short-circuit current peak value (Case 5) is only 86 per cent of the three-phase short-circuit peak, Case 9. Furthermore, the current wave of Case 5, Fig. 5, is more peaked than that of Case 9, Fig. 8, so that the effective value of the initial single-phase short-circuit current, Case 5, will be less than 86 per cent of the initial three-phase short-circuit current. Therefore, at the initial short circuit an armature coil in a single-phase generator will have only about half as much heat to dissipate as an armature coil in a three-phase generator. However, a study of a large number of oscillograms shows that the initial single-phase short-circuit current is practically the same as the three-phase short-circuit current.

The five assumptions which the author made in deriving the formulas are reasonable and they should not introduce an appreciable error in most cases. These assumptions must be made if a simple and practical solution of such a complicated problem is to be obtained. There are, however, a few cases which might be mentioned as a matter of interest in which different results are obtained in practise from those given by the formulas. I refer to the sustained short-circuit armature current waves of Cases 1, 2, 3, 4 and 5 shown by Figs. 9, 10 and 11 which show symmetrical short-circuit current waves. Fig. 1 accompanying this discussion shows a typical sustained armature current wave corresponding to the author's Case 5, Fig. 11, of a cylindrical-rotor generator without a pole-face damper winding. The five assumptions are realized in this type of a machine more than in any other type. Contrary to Fig. 11, Fig. 1 herewith is not a symmetrical wave and it contains cosine terms as well as sine terms. Fig. 2 herewith shows a typical sustained short-circuit current wave corresponding to Case 5, Fig. 11, of a salient-pole machine without a pole-face damper winding. Fig. 2 herewith is a symmetrical wave, but this machine does not fulfil condition *D* of the paper.

1. Page 855.
2. Page 863.

Fig. 14 of the paper shows the same short-circuit current waves for both Cases 8 and 9. For Case 8 the short-circuit armature current wave is rarely a sine wave as shown by Fig. 14. The short-circuit current wave for Case 8 usually contains a negative third harmonic which gives a peaked wave as shown by the accompanying Fig. 3. For Case 9 the sustained short-circuit current wave is practically a sine wave as shown by the accompanying Fig. 4. It should be noted that this Fig. 4 agrees with Fig. 14 in the paper.

Fig. 1—Sustained Single-phase, Short-Circuit Current, Terminal to Terminal, (Case 5). Cylindrical Rotor Generator without Damper Winding

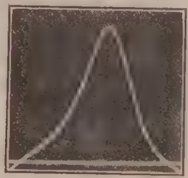

Fig. 2—Sustained Single-Phase Short-Circuit Current Terminal to Terminal (Case 5) Salient Pole Generator without Damper Winding

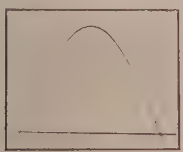

Fig. 3—Sustained Three-Phase, Short-Circuit Current, Neutral Connected (Case 8) Generator without Damper Winding

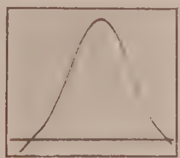

Fig. 4—Sustained Three-Phase, Short-Circuit Current, Neutral not Connected (Case 9) Generator without Damper Winding

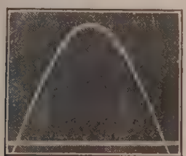

Fig. 5—Sustained Single-Phase, Short-Circuit Current, Terminal to Terminal (Case 5) Cylindrical Rotor Generator with Damper Winding

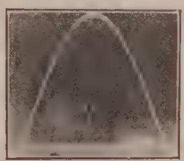

Fig. 6—Sustained Single-Phase, Short-Circuit Current, Terminal to Terminal (Case 5) Salient Pole Generator with Damper Winding

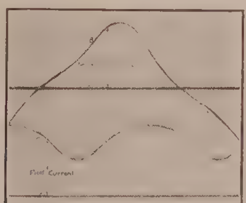

Fig. 7—Sustained Two-Phase, Short-Circuit Current of a Three-Phase Generator between Two Terminals and Neutral, without Damper Winding

In addition to the five assumptions made in deriving the formulas of this paper, there is another assumption which the author made but apparently neglected to mention, namely, that the machines have no pole-face damper windings. All synchronous motors are furnished with pole-face starting windings and many generators have pole-face damper windings. If the machines whose sustained short-circuit armature current waves are shown by Figs. 1 and 2 herewith are equipped with pole-face windings, the short-circuit current waves will now be as shown by Figs. 5 and 6 herewith respectively. It is apparent that these waves are as nearly true sine waves as can be obtained. The addition of a good damper winding short circuits the double-frequency armature-reaction component which induces (by transformer action) a triple-frequency voltage in the armature winding. Since the phase belt is 120 deg. (Case 5) the third-harmonic voltage induced (by dynamic action) in the armature winding by the third harmonic of the flux wave cannot appear at the terminals of the machine. Consequently, a nearly true sine wave of current results.

Fig. 16 of the paper shows an oscillogram of the sustained two-phase short-circuit currents of a three-phase alternator short-circuited between two terminals and neutral, Case 7. It is pointed out in the paper that the alternating component induced

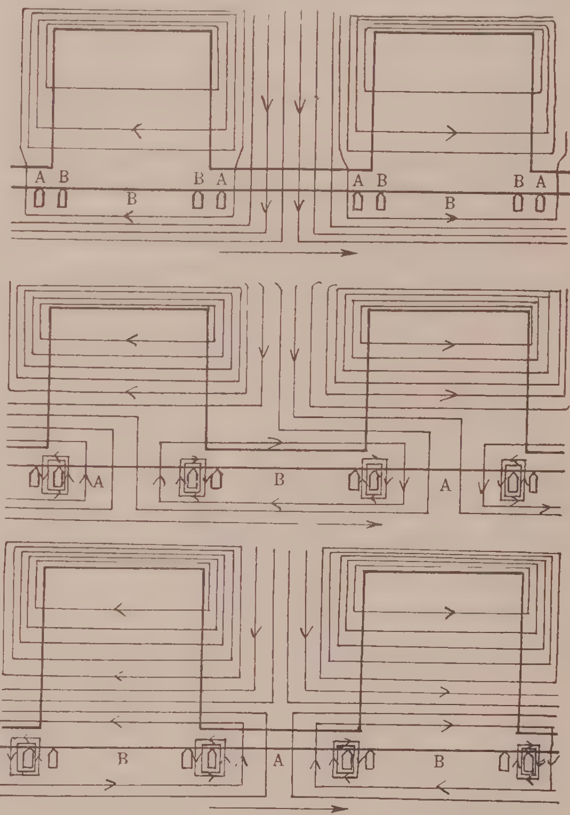

Fig. 8—Diagram Showing Continuity of Flux Leakages During Short Circuit

in the field winding in this case is very small and the field-current Curve *A*, Fig. 13, is shown as a straight line. Fig. 16 shows a double-frequency component in the field current of only plus or minus 9 per cent. The generator which was used in this particular case was equipped with a pole-face damper winding which tends to damp the single-phase double-frequency pulsations in the field circuit. Fig. 7 herewith shows an oscillogram of the armature current and field current for the same conditions as shown by the author's Fig. 16 taken from a generator which had no pole-face winding. It should be noted that the variation in the field current is plus or minus 33 per cent. Therefore, Case 7 is in reality a partial single-phase load (the two armature currents being out of phase by 120 deg.) and results in the usual double-frequency pulsation in the field winding. Of course,

Case 7 does not give so great a double-frequency pulsation as Cases 3 and 5, but it is decidedly more than Cases 8 and 9. If the value of the coupling coefficient K is calculated for this particular machine, it is found to be from -0.35 to -0.40 instead of cosine 120 deg. which equals -0.5.

J. F. H. Douglas (by letter): The points that impress one most forcibly in Professor Karapetoff's paper are the mathematical elegance and the generality of the relations discussed, together with the space-vector diagrams. There are a few points which I should like to mention.

In the first place it should be noted that the equations (**21**) to (**25**) are really of great simplicity. The chief difficulty in the appendices that follow lies in the determination of the constants of integration. Whether one reads the latter appendices or not, the first appendix should be of great general interest, in that it proves the general principle involved.

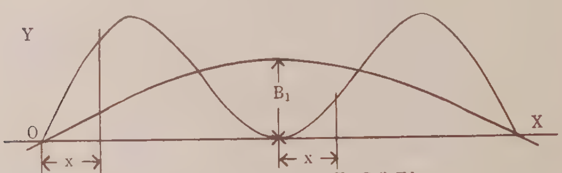

Fig. 9—Transverse Flux Wave Shape

The physical interpretation of Equations (**21**) to (**25**) is that there is continuity and approximate constancy in the linkages existing at the instant of short circuit, so that, the armature drags its linkages around with it. A picture of my interpretation of these equations is shown in Fig. 8 herewith, where a two-phase machine is shown with 50 per cent pitch armature coils. At the top of the picture are shown conditions at instant of short circuit. Phase A links with useful flux, phase B with no flux and the field with the total flux. Phase A has no leakage locally around the slots at this instant. The middle figure shows flux lines 90 deg. later in time phase. Phase A has dragged its linkages around into the interpolar region. Phase B has reflected or warded the pole flux away from entering the armature. The lowest portion of the figure shows flux lines 180 electrical degrees from the start. Phase A is now feeding flux into the pole, and the leakage flux is immensely increased, both locally and between the poles. This picture shows perhaps more clearly than any formula the advantage of having the values of σ and τ less than one and a value of K considerably less than unity, if possible. It is readily seen that the values of armature current and field current corresponding to the bottom diagram must be very large to force the flux through paths of such high reluctance. A similar condition obtains in the case of a machine with a distributed field.

In the fifth paragraph of the paper the assumption is made that the field winding is placed upon a cylindrical rotor, so that the self and mutual inductances of the armature windings may be considered to remain constant throughout a cycle. These constants are treated as absolute constants, however, and so it may be said that saturation is also neglected. These assumptions are the same assumptions upon which the idea of "synchronous impedance" is based. The first of these assumptions is not true in any machine, for normal field currents. The principle of continuity in the linkages existing at short circuit, would tend to perpetuate saturation existing at the instant of short circuit. Nevertheless, the assumption of uniform air-gap permeance, constant inductances, and synchronous impedance, based upon them, all are useful as first approximations.

As a second approximation, in the case of sinusoidal and steady load currents, I have found the idea of synchronous impedance useful even in the case of salient-pole machines, because of its simplicity. But, one must point out that at high saturations the numerical value of this constant is reduced, and that at high power factors the numerical value is also decreased. Whether, this same second assumption of an average and constant L is also applicable to the case of the transient condition of short circuit I am not prepared to state. It would certainly be some simplification in the theory if it should prove to be the case.

It occurs to me that a third approximation ought to take in the variation of the permeance of the air gap with the angle from the pole center. Perhaps this can be best done by considering the flux resolved into two components, along the polar, and transverse to the polar axis. The flux produced by the direct ampere-turns, may be considered substantially as sinusoidally distributed, while that caused by any transverse ampere-turns may be considered as distributed as in Fig. 9 herewith, the equation of which is $Y = B_1$ ($\sin x + \sin 3x$).[1] The m. m. fs of the armature are to be thought of as sinusoidally distributed, the direct flux as sinusoidal, but the transverse flux as non-sinusoidal.

Let us assume a two-phase machine, with the windings identical, and displaced 90 deg. on the armature surface. Let, τ, σ, N_a, N_f, I_f, i_f, L_a, L_f, α, have the meaning in Prof. Karapetoff's article. Let the direct flux be ϕ_d, the transverse ϕ_t[1]. Let χ be the ratio of the transverse flux set up by 1 ampere-turn to the direct flux (sine-wave component). Let the arrangement of the circuits be as shown in Fig. 10 herewith. Then we should note that equations (**1**), (**2**), (**3**), (**10a**), (**10b**) and (**10c**) are not correct, since although M_{ab} would appear to be zero, there is mutual induction between the phases owing to differing air-gap permeance in different directions.

$$\phi_t = \chi\,(L_a/N_a)\,(i_a \sin \alpha - i_b \cos \alpha) \tag{1}$$

$\phi_d = (L_a/N_a)\,(i_a \cos \alpha + i_b \sin \alpha), + i_f\ \tau\ L_f/N_f$ linking with armature (2)

$\phi_f = (L_a\,\sigma/N_a)\,(i_a \cos \alpha + i_b \sin \alpha) + i_f L_f/N_f$ linking with field (3)

The linkages in phase with a coil in position x is, of course,

$$\phi_x = \phi_d \cos x + \phi_t\,(\sin x - 0.33 \sin 3x) \tag{4}$$

When x is changed to α equation (**4**) herewith becomes equation for ϕ_a.

To find ϕ_b we let x = 90 deg. $- \alpha$, and get

$$\phi_b = \phi_d \sin \alpha + \phi_t\,(\cos \alpha + 0.33 \cos 3\alpha) \tag{5}$$

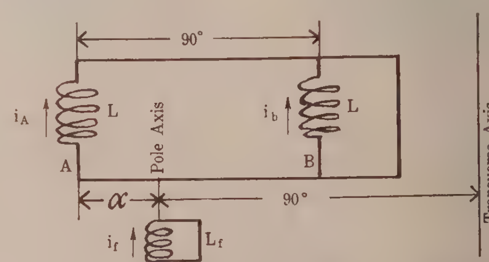

Fig. 10—Diagram of Two-Phase Alternator

If the initial value of the field current if I_f and the short circuit occurs when the phase a is in maximum linkage with the pole.

$$\phi_f = I_f\, L_f/N_f, \quad \phi_b = 0, \quad \phi_a = \tau\, I_f\, L_f/N_f \tag{6}$$

The constants in equations (**3**), (**4**) and (**5**) herewith, are given in (**6**) or in similar equations for other initial conditions. The variables ϕ_t and ϕ_d can be obtained from equations (**1**) and (**2**) These equations contain only three unknown quantities i_a, i_b, and i_f, and therefore, permit us to solve simultaneously. Rather, however, pursuing the matter further, I call upon Professor Karapetoff to state, whether in his judgment, this reasoning is valid and if it would, or would not, lead to materially different results.

1. Distribution of Φ_t is in accordance to density ($\sin x + \sin 3x$) and according to linkage ($\sin x - \frac{1}{3} \sin 3x$).

It is interesting to note that in equations (**10a**) and (**10c**) if θ_{ab} and θ_{ac} are each 120 deg. and if $N_a = N_b = N_c$, that $M_{ab} = M_{ca} = -0.5\,L_a$. It is interesting also to note that equation (**1**) might apply individually to phases even though a short circuit were not present. In equation (**1**) if we let $L=0$, and remove the short circuit, the voltages e are replaced by e_a, e_b, e_c. Let us now assume, that i_a, i_b, and i_c, are sinusoidal, equal in magnitude, and displaced by 120 deg. time phase, then

$$(d\,i_b/d\,t) + d\,i_c/d\,t = -(d\,i_a/d\,t),$$

$$d\,i/d\,t = j\,2\,\pi\,f\,\dot{I} \text{ and } d\,(M_{af}\,i_f)\,d\,t = \dot{E}_o$$

and equation (**1**) reduces to the familiar form

$$\dot{E}_o - j\,2\,\pi\,f\,(3/2)\,L_a\,\dot{I}_a = \dot{E}_a \qquad (7)$$

Or, stated in words, the terminal voltage in any phase with

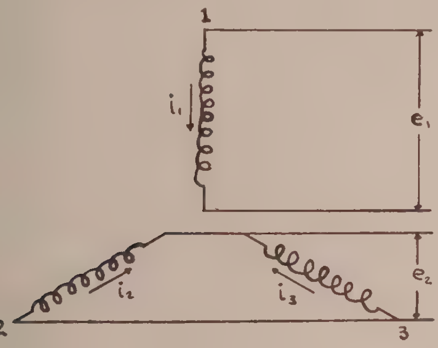

FIG. 11

balanced load, is equal to the voltage induced in that phase at no load, minus a drop in time quadrature with the current, a drop which is usually called the synchronous reactance drop.

Inasmuch as I have been questioned by Professor Karapetoff in discussion of a recent article of the JOURNAL for the use of synchronous impedance even as a second approximation, I should like him to explain clearly for the benefit of the readers of the JOURNAL his position on this subject so far as it is implied in his paper.

R. H. Park (Communicated after adjournment): On the second page of his paper in referring to the coefficient of coupling between the phases of an alternator, Mr. Franklin states,

"Thus, for a three-phase alternator, this coupling coefficient was assumed equal to cos 120, or -0.5. This ideal value of coupling is seldom obtained in practise."

Actually, it may be shown that for a symmetrical three-phase alternator the numerical value of the mutual inductance M between phases must be less than the self inductance L per phase, that is, $L + 2\,M > 0$.

For suppose the alternator of Fig. 11 herewith to be used as a transformer, power being supplied to Phase 1 as the primary and taken from Phase 2 and 3 in parallel as the secondary.

The statement of Kirchoff's law is for the primary,

$$r\,i_1 + L\frac{d\,i_1}{d\,t} + \frac{M\,d\,(i_2 + i_3)}{d\,t} = e_1$$

and for Phase 2 of the secondary,

$$r\,i_2 + L\frac{d\,i_2}{d\,t} + \frac{M\,d\,(i_3 + i_1)}{d\,t} = e_2$$

But by symmetry it follows that the currents in Phases 2 and 3 are equal, that is, $i_2 = i_3$. Substituting and rearranging gives,

$$r\,i_1 + L\frac{d\,i_1}{d\,t} + \frac{M\,d\,(2\,i_2)}{d\,t} = e_1 \qquad (c)$$

$$r\,i_2 + \frac{L+M}{2}\frac{d\,(2\,i_2)}{d\,t} + \frac{M\,d\,i_1}{d\,t} = e_2 \qquad (d)$$

Since in equation (**d**) $2\,i_2$ represents the total current entering the secondary of the transformer, $\frac{L+M}{2}$ becomes the equivalent self-inductance of the secondary of the transformer.

In order that the coefficient of coupling of the transformer shall be less than unity, it is necessary that $L_1\,L_2 > M^2$ where L_1 is the primary and L_2 the secondary self-inductance and M is the mutual inductance of transformer. Therefore it follows that

$$L_1\,L_2 = \frac{L\,(L+M)}{2} > M^2 \qquad (e)$$

$$L^2 + L\,M - 2\,M^2 = (L - M)\,(L + 2\,M) > 0 \qquad (f)$$

or since M is essentially negative $L + 2\,M > 0$.

N. S. Diamant (by letter): One of the interesting features of these papers is the extensive use of the ideas of mutual and self inductance and fluxes instead of reactances. There was a time when the use of these more elementary notions was not very popular and we had to use reactances and impedances. In this connection Prof. Karapetoff's method of dealing with permeances is very interesting and should prove useful. After a little practice the expressions (**7**) to (**11c**) should prove very simple and useful in general engineering work. One of the great advantages of such expressions is the fact that they keep before us a clear mental picture of the underlying physical phenomena. In this connection it is very important to remember the meaning of $K = M^2/L_f\,L_a$. If $K = 1$ then $M^2 = L_f\,L_a$ and there is no leakage flux between armature and field; this is a condition never realized and thus K is always smaller than 1 and $K^2 = \sigma\,\tau$ where σ and τ are the leakage coefficients for the armature and field respectively.

The fundamental treatment of the subject is the same in both papers although equations (**1**) to (**4**) of Prof. Karapetoff have been written in terms of e. m. f. and Mr. Franklin's equations (**3**) to (**6**) in terms of flux. For example, translating into English equation (**1**) of Prof. Karapetoff we have: e. m. f., e induced in phase A = the e. m. f. of self-inductance of phase A + the e. m. f. of mutual inductance of phases B and C + the e. m. f. of rotation due to the field flux. Similar to this is Mr. Franklin'- equation (**113**) for a three-phase alternator or the simple equas tions (**3**) to (**6**).

Returning to Prof. Karapetoff's fundamental equations, it

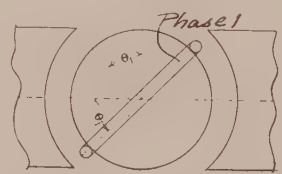

FIG. 12—CONDITION ASSUMED FOR DISCUSSION

may be well to call attention to the fact that the total induced e. m. f., e is arbitrarily assumed to be a function of s and to be equal to $S + A$ for phase A; $S + B$ for phase B, etc. Then the value of s is taken as equal to S at the instant of short circuit and a new arbitrary relation involving angle ξ is introduced in equations (**26**) to (**28**).

Translating this statement into mathematical shorthand we obtain:

$$L_a\,i_a + M_{ab}\,i_b + M_{ca}\,i_c + M_{fa}\,i_f = (N_a\,\Phi\,\sin\,\omega\,t)\,\epsilon^{-\alpha_a(t-t_1)}$$

for phase A, and similar expressions for the other phases. For the field we have:

$$L_f\,i_f + M_{fa}\,i_a + M_{fb}\,i_b + M_{fc}\,i_c = N_f\,[\,\Phi_{fssc} + (\Phi_f - \Phi_{fssc}\,)\,\epsilon^{-\alpha_f(t-t_1)}]$$

I have used the same notation as Prof. Karapetoff and t_1 or θ_1 is the time or the corresponding time angle at which the sudden short circuit occurs.

All this is very good, but an engineer will do well to keep in mind always the physical meaning and interpretation of the fundamental equations. Unlike the pure mathematician, when an engineer introduces arbitrary functions, he will do well to try to understand the physical side of his mathematics. If he does not, he will be merely riding through a tunnel, having left the light behind him and he may emerge again into light or he may not. I have tried to look over Prof. Karapetoff's paper from this point of view of coordinating mathematics with their physical meaning and although I had some difficulty in understanding the physical meaning of the functions introduced, no doubt this was my fault. Prof. Karapetoff with his usual clearness no doubt

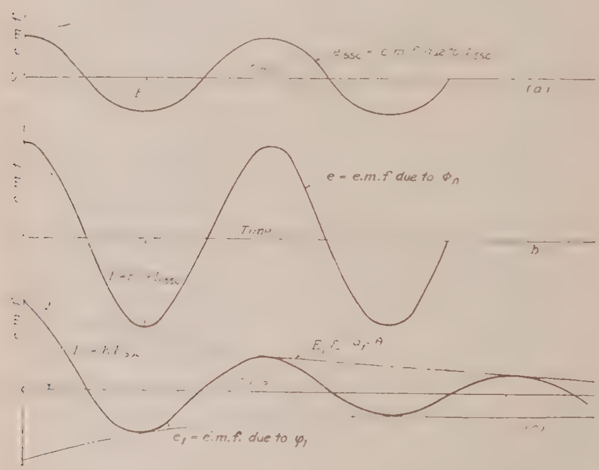

FIG. 13—E.M.FS. PRODUCED BY CONDUCTORS CUTTING ϕ_{ssc}, ϕ_n AND $(\phi_n - \phi_{ssc})$

has presented the subject thoroughly but it may require more study to understand the physical meaning of all the fundamental concepts involved.

There is another very important point to be considered in connection with these papers, namely, that they give expression for instantaneous and sustained short-circuit currents but none for the transient.

It is simple to obtain the fundamental expression whose solution will give the transient currents as well as their initial and final values. Consider one of the phases of a three-phase alternator and suppose that phase No. 1 is at the position indicated in Fig. 12 herewith, when the three phases are suddenly and simultaneously short-circuited. Assuming a sinusoidal flux distribution, the flux inclosed by phase No. 1 at the instant of the short circuit will be:

$$N_a\,\Phi_a \sin \omega\, t_1 = N_a\,\Phi_a \sin \theta_1$$

where $N_a\,\Phi_a$ = maximum flux inclosed by the N_a turns of any given phase. The flux inclosed by phase No. 2 at the instant of the sudden short circuit will be $N_a\,\Phi_a \sin(\theta_1 + 2\,\pi/3)$, and similarly for the third phase.

As is well known, the flux inclosed by any given phase under sustained short circuit is a very small fraction of $N_a\,\Phi_a$. Therefore, if it is assumed that the sustained short-circuit armature reaction (*a*) is wholly demagnetizing (*b*) and sinusoidally distributed like the field flux, and that (*c*) *the armature resistance drop is negligible compared to the reactance drop*; then a little consideration will show that the armature flux under sustained short circuit will be zero. Thus the flux linking with phase No. 1 is $N_a\,\Phi_a \sin \theta_1$, at the instant of the sudden short circuit when $t = t_1$; it is reduced to zero at the end of the short circuit when $t = \alpha$, and it is $(N_a\,\Phi_a \sin \omega\, t)\,\epsilon^{-\alpha_a(t-t_1)}$ at any time t during the interval of sudden short circuit, α_a being the attenuation factor of the armature. Under normal or transient conditions the *flux linking phase No. 1 is equal at every instant to the mutually inductive flux coming from the field plus the self-inductive flux of phase No. 1 itself.* The corresponding condition holds true for the other phases. Compare Karapetoff's equations (1) to (4).

The field flux, which is $N_f\,\Phi_f$ under normal conditions, dies down to $\Phi_{fs\,c}$ at the end of the sudden short circuit or at the beginning of the sustained short circuit; at any time after the sudden short circuit it is equal to (See Fig. 14)

$$\Phi_f = \Phi_{fssc} + (\Phi_f - \Phi_{fssc})\,\epsilon^{-\alpha_f(t-t_1)}$$

where α_f is the attenuation factor of the field. Under normal or transient conditions this flux *is equal at every instant to the mutually inductive flux coming from the three phases plus the self-inductive flux of the field itself.*

With reference to Table II in Mr. Franklin's paper it was very gratifying for me to see that Cases 3 and 5 act so differently. In 1915 I had noticed this and in view of my meagre data stated: "the case of single-phase short circuits, between two terminals or terminal and neutral, present considerable difficulties; the latter seems to give much higher current rushes than a short circuit between terminals," and as seen from the table the ratio is 1 to 1.732.

The sustained short-circuit phenomena are very interesting and particularly the flux distribution is quite fascinating. As a result of a fairly elaborate investigation I had shown in 1918[2] that the armature current and the e. m. f. waves may be nearly sinusoidal but the resultant flux wave may be extremely distorted for the simple reason that with the very low voltages which obtain under s. s. c. conditions the fundamental is so greatly reduced that the higher harmonics assume a very predominant role. For example if the field flux consists of: Fundamental, 100 per cent; third harmonic + 10 per cent, and fifth harmonic + 5 per cent, while the armature flux consists of: Fundamental − 95 per cent; third harmonic, + 10 per cent, and fifth harmonic, + 5 per cent; then the resultant will be: Fundamental, + 5 per cent; third harmonic, + 20 per cent and fifth harmonic, + 10 per cent, — which will be a very distorted wave.

C. M. Lafoon (by letter): The general method of solution as used by Mr. Franklin in determining the magnitude of the short-circuit currents during the first cycle after the short-circuit occurs is the same as was used in my paper[3] on the same subject at the

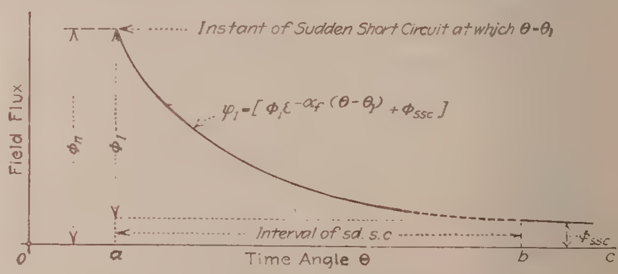

FIG. 14—ATTENUATION OF FIELD FLUX

1924 Midwinter Convention of the A. I. E. E. Moreover, the various cases of generator winding combinations and short-circuit conditions are also practically the same.

The expressions for the maximum or peak values of the short-circuit waves as derived by Mr. Franklin are in general, the same as given in my paper. However, there are two features or discrepancies which it is necessary to call attention to. It is indicated in Table II that the peak value of the current in the case of a single-phase short circuit between main terminals is irrespective of the width of the single-phase winding belt. The general

2. Sustained Short-Circuit Phenomena and Flux Distribution of Salient-Pole Alternators, by N. S. Diamant, A. I. E. E. TRANSACTIONS. Vol. XXXVII, page 1141.

3. Short-Circuits Current of Alternating-Current Generators, by C. M. Lafoon, A. I. E. E. JOURNAL, August 1924, page 737.

expression for the peak value of the armature current in a single-phase short circuit is

$$i_a = \frac{2\, I_f\, M_o}{L_a - \dfrac{M_o^2}{L_f}}$$

Hence in order for the armature current of a single-phase generator with any width of winding belt to have a constant ratio with respect to a terminal-to-terminal three-phase short-circuit current, it is necessary for both numerator and denominator of the above expression to vary in the same way with respect to the width of the winding belt. There can be no question but that

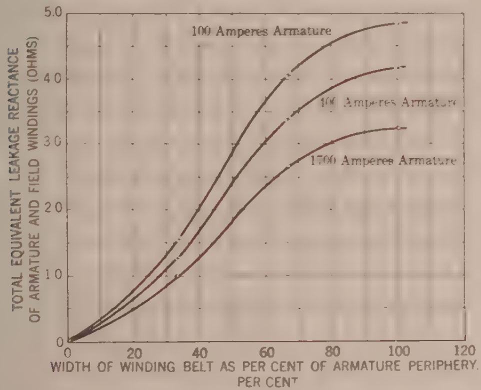

FIG. 15—TOTAL EQUIVALENT LEAKAGE REACTANCE OF ARMATURE AND FIELD WINDINGS COMBINED. AXES OF TWO WINDINGS COINCIDE, SINGLE-PHASE ARMATURE WINDING

the quantity $2\, I_f\, M_o$, varies as the sine of the width of the winding belt. My analysis shows that the quantity $L_a - \dfrac{M_o^2}{L_f}$ varies approximately as the sine-square of the width of the winding belt. These relations are shown in Figs. 18 and 19 of my original paper. The general shape of the curve of $L_a - \dfrac{M_o^2}{L_f}$ as a function of the width of the winding belt has been checked experimentally by (a) locking the rotor so that the axis of the field winding coincides with the axis of the portion of the armature winding under consideration; (b) short-circuiting the field-winding; and (c) then applying single-phase voltage to the armature winding. The test results which were obtained on a 6250-kv-a. turbo generator are shown in Figs. 15 and 16 herewith. On this basis, the general relations between the different armature currents of a single-phase generator with different widths of winding belts are shown in Fig. 5 of my paper.

In my paper, the maximum value of the armature current for a three-phase alternator when the short circuit occurs between terminals as given in Case 10 of Table I is based on the condition that the short circuit occurs when the axis of the field winding coincides with the axis of the portion of the armature winding included between two main terminals. If the short circuit occurs at the instant when the axis of the field winding coincides with the axis of one phase, terminal to neutral, the peak value of the maximum current will be the same as in Cases 7, 8 and 9 of my paper and Cases 8 and 9 of Mr. Franklin's paper.

V. Karapetoff: In my paper I assume that there is no saturation and no salient poles, but, as has been pointed out by Professor Douglas before this problem is finished, we ought to extend the solution to machines with definite poles and machines involving saturation. In the initial short circuit, if there is saturation in the beginning and the field persists, that field will also contain saturation, after the instant of short circuiting. Mr. Franklin points out in his paper that this factor may be approximately taken into account by properly modifying the values of self and mutual induction.

Another answer to Professor Douglas is this: When we investigate the operation of a machine under normal conditions, we want to know its characteristics more or less exactly, but in the case of a short circuit, the indefinite resistance of the leads and of the nature of the phenomenon itself are such that we can seek hardly a definite solution, but only a possible maximum. So that no such accuracy is required in problems involving short circuits as in problems referring to operating conditions.

Mr. Doherty wishes to know why I start with differential equations rather than using directly the condition of constant magnetic linkages. One reason is that in most of our problems we have resistance as a factor, and for one problem that involves no resistance, I probably have a dozen which contain resistances. So it seems more natural always to start with Kirchoff's Law. The other reason is this: In a star-connected combination, constant flux linkages refer to a closed circuit, which, in this case, contains two phases in series. Two equations of constant linkages may be written, and these equations will contain, say, phase No. 1 twice; but phases No. 2 and No. 3 only once. Therefore, the equations are not symmetrical. From a mathematical point of view, it is better to have symmetrical equations, and this is done in my paper by introducing an auxiliary voltage e. However, I grant that it is possible to introduce a fictitious flux Φ and in this manner keep the flux equations symmetrical. In

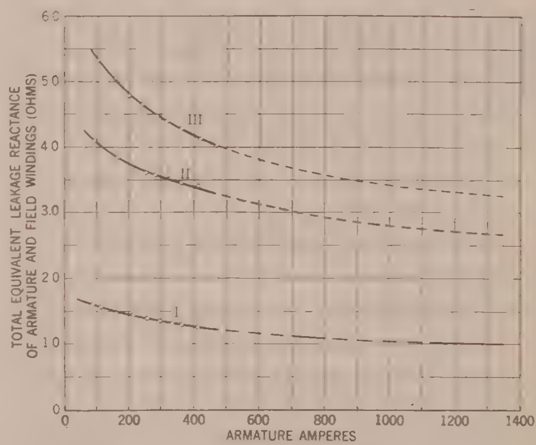

FIG. 16—TOTAL EQUIVALENT LEAKAGE OF ARMATURE AND FIELD WINDINGS COMBINED. AXES OF TWO WINDINGS COINCIDE. SINGLE-PHASE ARMATURE WINDING

I. One-Third of Armature Conductors in Series
II. Two-Thirds of Armature Conductors in Series
III. Three-Thirds of Armature Conductors in Series

other words, inst ead of writing the flux linkage equations in th form

$$\Sigma\,\Phi_1 - \Sigma\,\Phi_2 = \text{Const.}$$
$$\Sigma\,\Phi_1 - \Sigma\,\Phi_3 = \text{Const.}$$

they can be written in the symmetrical form

$$\Sigma\,\Phi_1 = \Phi + A$$
$$\Sigma\,\Phi_2 = \Phi + B$$
$$\Sigma\,\Phi_3 = \Phi + C$$

R. F. Franklin: The method of solution is, as stated in the introduction, the same as that used several times by R. E. Doherty in the solution of various kinds of short-circuit problems, and by C. M. Laffoon in his recent paper on alternator short-circuit currents. However, whereas Mr. Laffoon's paper deals principally with formulas for initial values and a physical

interpretation of short-circuit phenomena by the constant-linkage method, the present paper gives the derivation of the formulas for the instantaneous values of both the initial and sustained short-circuit currents for all the ordinary alternator connections. These formulas will be found very valuable to the designer in many problems where a knowledge of short-circuit currents or forces is desired.

I am indebted to Mr. Laffoon for calling attention to several errors in the table of maximum peak values of initial short-circuit currents (Table II). The wrong ratios were those for the single-phase and two-phase alternator cases which should have been divided by 2 and $\sqrt{2}$ respectively in order to reduce them to the bases of constant conductors per inch. This revision has been made in Table II. The value for the single-phase alternator case (case 1) depends upon the width of the phase belt as also pointed out by Mr. Laffoon. The width of the phase belt for the ratio given in Table II is 180 deg.

DISCUSSION ON POWER PLANT DESIGN
and on the paper
TRENTON CHANNEL STATION[1]
(Hirshfeld)

St. Louis, Mo., April 13, 1925

H. W. Eales: Cahokia Station of the Union Electric Light & Power Company is on a site of 51.6 acres on the Illinois bank of the Mississippi River ¾ mi. south of the Municipal Bridge and within 2½ mi. of the City Hall of St. Louis. There are available to it unlimited quantities of cooling water, both rail and river transportation for fuel, and unrestricted egress for either submarine or overhead circuits of any practicable voltage. Its location is, therefore, strategic from both the standpoint of economical production and distribution of power. The lack of all restrictions on the character of the electrical circuits affords all physical opportunity for high-voltage interconnection at the plant with any other system in Illinois.

The foundations for the Cahokia plant presented great difficulties on account of (1) the sand and silt character of the river bed, (2) the great variation in river level (43 ft. maximum during the year) and (3), the tremendous scouring action of the river. During the construction work soundings in the river varied as much as 25 ft. overnight.

The plant has been built upon concrete piles driven under those parts of the plant which are normally in the river to within 15 ft. of bed rock and to a lesser depth under the boiler house. To confine the sand about these piles an apron river wall has been employed consisting of reinforced concrete interlocking piles also driven to within 15 ft. of rock. The plant is on the outside of a bend in the Mississippi River so that there is full assurance of water supply, but with it an unusual scouring action north of the plant. The protection against this requires description since it is not all apparent from casual inspection.

The river bottom was dredged out along the plant apron wall to a depth 10 ft. below the intakes and a willow mattress 75 ft. in width was then placed on this bottom and loaded down with riprap. This mattress extends north on the upstream side of the plant for a distance of 250 ft. At this point a substantial permeable dyke or hurdle has been constructed. The outer part of this dyke consists of a double row of 80-ft. reinforced concrete piles driven so as to have a penetration of approximately 40 ft. The portion of these piles above the river bottom were tied together by heavy slabs or decks of reinforced concrete. A renewable bar screen of 1¼-in. galvanized steel rods was installed between the concrete decks along the entire upstream side of the structure so formed. Concrete protection work extends shoreward to a point corresponding to average water's edge. Extending from this point up the remainder of the river bank, the hurdle consists of wood piles driven in clusters on a batter and also laced together with horizontal piles. Substantial amounts of riprap were placed around these wooden piles.

The plant equipment and fundamental operating arrangements have been described in *Electrical World* issues of March 29th, 1924, and April 5th, 1924, and in January 22nd, 1924 issue of *Power*. The water-treating process is described in an article by E. H. Tenney in *Power* April 22nd, 1924, issue. It is only necessary at this time to bring the previous descriptions up-to-date and perhaps point out the high spots of the arrangement.

The building is being constructed in unit sections, each section more or less complete in itself and each containing two main turbine units with corresponding boiler and switchhouse equipment. Each building section has its own water intakes, the discharge, however, being common to the entire plant. One duplicate coal elevator and conveyor system supplies crushed coal to the raw-coal bunkers of two building sections. The car dumper is approximately at the middle of four building sections and will supply all four.

At present, two building sections are completed and foundations finished for Section III; three 35,000-kw. turbines are in operation and a 40,000-kw. unit is nearly ready for operation.

Two 2000-kw. house turbines are installed in the first building section and their electrical connections arranged to extend throughout the completed building. One of these units is kept in operation continuously to assure local power supply for station auxiliaries. Virtually all auxiliaries are electrically driven. Due to the use of house turbines in building Section I, the main turbines are bled at one point. Due to absence of house turbines in building Section II, the main turbines in that section are bled at four points.

The boiler house was designed initially for the use of pulverized fuel, the pulverizing department being contained in the eastern bay of the boiler house. At present, twelve 1800-h. p. boilers are in operation at 330-lb. gage pressure. Four similar units are now being installed. No air preheaters are used as that term is ordinarily understood; no economizers are used, as their installation was not justified in view of the relatively low-priced fuel used. Natural draft is employed for combustion which requires stacks 350 feet above the lowest point of furnace chamber. Plant Section I contains eight 6-ton-per-hour coal pulverizer mills and one 15-ton unit. Plant Section II contains three 15-ton mills and one 20-ton mill with one 20-ton mill still to be installed. The coal is dried in its passage from the raw-coal bunkers to the pulverizer mills by direct contact with some of the stack gases of the east row of stacks which is by-passed through the dryers for this purpose. The pulverized-coal transport and burning systems were based upon a storage system of pulverized coal. The storage bins above the furnaces have a capacity of about eight hours supply for the boilers when run at 250 per cent rating. The boiler controls are arranged for automatic operation as far as that is practicable at this time. The ashes and slag are dumped into a sluicing system on the bottom floor of the boiler house and sluiced out to a sump in the yard, where the large slag pieces are screened out by a bar screen and the finer material is pumped out into the river with a dredge pump. The slag left in the sump is taken out with a grab bucket and used on the property for fill and track ballast. The first eleven boilers each have a vertical water screen up the back wall of the furnace and a horizontal screen across the top of the ash pit. No. 12 boiler in addition to the screens above mentioned, has fin-tube water screens on the two sides. Furnaces for boilers No. 13 to No. 16 inclusive will be arranged similarly to No. 12.

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1. A.I.E.E. Jour. July, 1925. When the paper *Trenton Channel Station* was presented informal descriptions of several other plants were also given in order to allow comparisons between different types of design. These informal descriptions are published herewith as discussion. Information on the Weymouth Station of the Edison Electric Illuminating Company of Boston, contributed by I. E. Moultrop at this session, is not presented here because this station has been described extensively in the technical press including the A. I. E. E. Transactions, Vol. 42, page 621, 1923, *Some Engineering Features of the Weymouth Station of the Edison Electric Illuminating Company of Boston*, by I. E. Moultrop and Joseph Pope.

At present, the powdered coal enters the furnace from the top of the furnace near the front or "firing-aisle" side, this coal being forced in both by gravity and by primary-combustion air blown up from the basement from the ventilating ducts in the ash-pit walls. This results in the so-called "lazy combustion." Recent experiments in pulverized fuel combustion may result in a radical departure on succeeding boilers in the method of entrance and combustion of fuel.

The generation is at 13,800 volts, 60 cycles, and the switchhouse bus structure is arranged for that voltage. Isolated-phase arrangement of oil circuit breakers is employed with the phases separated vertically, the operating mechanisms being located on the lowest floor. Remote-control gang-operated disconnecting switches are used.

Power is transmitted to St. Louis entirely by means of submarine cables. At present, eighteen are in operation. All of these cables are 350,000 cir. mil. three-conductor cables and were designed for 33-kv. operation. Now, nine are in operation at 13.8 kv., four at 28 kv. and five at 33 kv. Six additional cables are to be installed this year. Each 13.8-kv. feeder has a reactor four per cent at 300 amperes.

Each cable has its own transformer for stepping up from 13.8 kv. to 33 kv. and the transformers are located on the river side of the switchhouse adjacent to the submarine-cable getaways. All transformers are of the forced oil-cooled type. They are three-phase type and are special to the extent that they are wound for 13.8 kv. delta and 33 kv. zigzag connection. This arrangement provides the high-tension neutral for grounding the cable system (each neutral being grounded solidly at the transformer) and also permits operation without phase displacement from primary to secondary, a condition which was requisite to permit parallel operation of 4500-volt distribution from circuits of the substation fed at 33 kv. from this station with 4500-volt circuits of substation fed at 13.8 kv. from the company's Ashley Street, St. Louis Station. Three transformers for the tie lines to Ashley Street Station are of 12,000-kv-a. capacity and all others 7500 kv-a.

Power transmission from the station to Illinois lines is by means of overhead circuits. The major supply to the City of East St. Louis is over two 33-kv. circuits through two three-phase 12,000-kv-a. self-cooled transformers units in the station yard. These transformers are connected in exactly the same manner as the transformers for the submarine cables. One 13.8-kv. overhead circuit supplies an automatic railway substation in East St. Louis.

In the station yard, there is now nearing completion an outdoor substation to step up from 13.8 kv. to 115 kv. for supplying power to a 30-mi. line which extends southwestwardly through Illinois to a point opposite Crystal City, Mo., where an overhead crossing of the Mississippi River is made. This transmission line initially will supply the Pittsburgh Plate Glass Company's load at Crystal City and the distribution system surrounding Crystal City and Festus, Mo. The initial load will be about 10,000 kv-a. The transmission line has been arranged for operation at 132 kv. The step-up plant at Cahokia contains two high-tension busses with two 12,000-kv-a., three-phase self-cooled transformers with oil circuit breaker equipment on outgoing lines, transformers, and bus junction position. All disconnecting switches will be motor-operated. The operation of circuit breakers and disconnecting switches will be carried out by the station benchboard operator by means of a supervisory control system.

The present plan of power house development provides for an ultimate building of four sections. The indications now are that turbine units larger than present units will be installed in Sections III and IV and that the total station capacity will then be about 350,000 kw. The unit plan of building extension provides all reasonable flexibility to permit advantage to be taken of any advance in the design of switchhouse, turbine or boiler-room; the only fixed dimension is in the width of the turbine room. Since the turbine shafts are parallel to the length dimension of the room, this places no practical limitation on its development. The present ground space is sufficient for five building sections of the present dimensions.

The station has had the usual temporary difficulties incident to installations while new, but at no time has the pulverized-fuel installation caused any interruption in the service from the station.

The operating results can best be appreciated by a glance at the accompanying table which indicates the performance and output of the station from January 1, 1924 to March 1, 1925.

OPERATING DATA ON CAHOKIA POWER STATION
UNION ELECTRIC LIGHT & POWER COMPANY OF ILLINOIS

1924	Max. Kw. Output Main Units	Kw-Hr. Generated Including House Turbines	Kw-Hr. Station Use	Kw-Hr. Net Output	B. t. u. Per Net Kw-Hr.	Circulating Water Temp. °F.	B. t. u. Coal as Received
Jan.	40,000	15,129,000	1,625,800	13,503,200	19,310	32	10,959
Feb.	45,000	16,712,000	1,536,100	15,175,900	17,579	35	10,831
Mar.	45,000	24,034,000	2,110,800	21,923,200	17,916	39	11,015
Apr.	52,000	25,452,000	2,126,400	23,325,600	17,343	53	11,164
May	60,000	25,546,000	2,041,100	23,504,900	17,408	60	11,018
June	60,000	25,811,000	2,126,400	23,684,600	17,735	72	10,933
July	60,000	26,536,000	1,631,800	24,904,200	17,802	76	10,928
Aug.	62,000	27,877,000	1,726,200	26,150,800	17,951	79	11,016
Sept.	64,000	28,866,000	1,643,900	27,222,100	17,403	69	10,787
Oct.	69,000	32,084,000	1,796,800	30,287,200	17,224	62	10,783
Nov.	80,500	33,481,000	1,816,400	31,664,600	17,290	49	10,793
Dec.	94,000	39,856,000	2,142,500	37,713,500	17,093	35	10,771
1925							
Jan.	93,000	40,677,000	2,110,225	38,566,775	16,895	32	10,666
Feb.	91,000	35,847,000	1,846,350	34,000,650	16,910	36	10,751

E. H. Tenney: The cost of preparation of pulverized coal at Cahokia during the past year, including all costs from the receipt of coal in the yard to the removal of ash from the ash pits, and also including power for driving the necessary auxiliaries, was 33.58 cents per ton. Of this the handling and preparation of raw coal was 6 cents per ton; the drying, handling and preparation of powdered coal 19 cents per ton, and power for all purposes 8.58 cents per ton.

The power required for handling coal was figured less space as follows:

	Kw Hr. per Ton
Unloading, conveying and crushing..........	0.4
Power for dryer fans........................	2.66
Mills and mill fans.........................	16.15
Air compressors.............................	6.48
TOTAL.......................................	25.69

It is anticipated that these figures will be reduced 4 kw-hr. per ton by the use of the 15-ton and 20-ton mills.

Of course, it will be understood that these are the actual figures that prevailed during the past 12 months and do not take into account what the cost might have been had the load factor on the equipment been up to its maximum possible figure. In other words, it would have been entirely possible to have taken a somewhat larger tonnage from these mills, but no adjustment whatever has been made in the figures.

With regard to the operation of the milling equipment at Cahokia, tests on the various sizes of mills indicate the following performance on the Raymond 6-ton mills:

Tons pulverized per hr.......................	6.85
Kw-hr. per ton...............................	17.4
Moisture in coal leaving mill (per cent).......	5.3
Gas Temp. inlet, deg. F......................	400
Gas Temp. outlet, deg. F.....................	165

Fineness, 65 per cent through 200-mesh screen

On the 15-ton Raymond mills, which have been in operation for ten months, the following performance figures taken from a test may be of interest:

Tons per hr..................................	16.3
Kw-hr. per ton...............................	15.0
Moisture in coal entering mills (per cent).....	9.8
Moisture in coal leaving mills (per cent)......	4.7
Temp. of gases entering dryer, deg. fahr.......	465
Temp. of gases leaving dryer, deg. fahr........	160

Fineness of coal, 66.75 per cent through 200 mesh screen.

Fuller 20-ton Mill: This has now been in operation about four months. Preliminary test showed the following performance:

Tons per hr..................................	23.5
Kw-hr. per ton...............................	14.6
Moisture in coal entering mill (per cent).....	10.0
Moisture in coal leaving mill (per cent)......	4.5
Temp. of gas entering dryer, deg. fahr........	340
Temp. of gas leaving dryer, deg. fahr.........	150

Fineness of coal, 62½ per cent through 200 mesh screen.

The lower gas temperature noted in the dryers of the Fuller mills is due to the difference in design of the drying equipment, which has resulted in the passing of more gas through the dryers to the Fuller mills than is the case with the Raymond equipment. Steps are now being taken to readjust the gas volume and temperatures with the expectation of increasing the drying effect which will result in a higher percentage of extremely fine coal, and probably a somewhat lower cost for power.

One other item that may be of interest is in connection with the quantity of air required for transporting powdered coal about the station which is now running approximately 1600 cu. ft. per ton.

The lubrication of the milling equipment, which has frequently been referred to as an item of expense of some importance, during the past year at Cahokia has been 0.6 cent per ton of coal.

C. G. Spencer: To make the discussion of Mr. Hirshfeld's paper specific, your chairman has asked that the reasons be given for certain differences in the basic design of Trenton Channel and Cahokia. He lists as the more obvious, the precipitation of ash from the stack gases, the separate preparation plant, the large type Stirling boilers fired from both ends, direct current for variable-speed essential auxiliaries, and single-pass condensers.

A brief survey of the controlling factors is necessary to discuss these particular points properly. The quality and cost of coal normally available at Trenton Channel and at Cahokia, represents the factor of widest divergence. Next and perhaps of equal importance is the physical condition of the sites upon which the two plants are constructed. Cahokia is located on the East bank of the Mississippi to secure a substantial saving on freight on coal from the Illinois fields. With this fixed, the proximity to the center of the load and due regard for condensing-water supply and rail connections were the controlling factors. The site selected was 15 ft. below the high-river stage of the Mississippi, with soil of no bearing value for 50 ft. underlaid by gravel.

This unusual combination of flood and foundation conditions affected the entire design of this plant, since the cost of foundations, substructure, and waterproofing made projected area rather than height the controlling factor in keeping building costs down, while at Trenton Channel with a constant level of condensing-water supply and favorable foundation conditions, economy was in the direction of an increased projected area.

Mr. Hirshfeld makes plain the third major factor controlling the design, namely, that Trenton Channel is located near a residential district while Cahokia's surroundings are largely given over to railroad yards and industry.

To take up your chairman's questions, the preceding paragraph explains in a general way why ash precipitation is not required at Cahokia. Further, the Cahokia stacks are referred to as the cleanest in the St. Louis district. The foundation and waterproofing problem is one controlling reason for including the preparation plant in the boilerhouse structure. A second and equally important consideration is the necessity for drying Illinois coal every day in the year, to do which economically requires waste-heat dryers located adjacent to the boiler uptakes. When the decision for boilers was made three years ago, the bent-tube or Stirling type of boiler had not been developed for the working pressure adopted at Cahokia.

Alternating current was selected for all auxiliaries, with the one exception of fuel-feeder motors, with the normal supply from house alternators and a secondary supply through transformers connected to the station bus as being lower in first cost and combining the required speed variation with a reliable supply.

The single-pass condenser does not lend itself to the deep-pit construction required at Cahokia by the 40-ft. variation in river level. The two-pass condenser, due to local conditions, was lower in first cost than the single-pass.

This frank discussion is made to clear up certain obvious questions that will be asked by those who study Mr. Hirshfeld's admirable description of Trenton Channel and who later visit Cahokia. This offers an excellent opportunity to stress the fact, so often overlooked, that local conditions govern station design costs and thermal efficiency to such an extent that generalizations and direct comparisons are not only valueless but dangerous, particularly in the hands of non-technical men. This applies to comparisons of station costs on a kilowatt basis and of thermal efficiency or B. t. u. per kilowatt hour both of which are being published from time to time without the supporting facts necessary for a proper interpretation. The real measure of a design is the cost of the product, the kilowatt hour sent out, with all items both fixed and operating included and not applied to the initial period of high load factor but over the life of the plant.

E. H. McFarland: Philo Plant of the Beech Bottom Power Company has many new features which may be of interest. The discussion is mainly on those plants adjacent to large cities with concentrated load demand of peaking character. Load factor and interconnections involving use of cable and various voltages have influenced design.

The recent large plants constructed by the American Gas and Electric Company serve directly steel-tower high-tension interconnected networks with freedom of interchanges and basic load

obtainable involving a high-percentage use of plant equipment. The Philo Plant for this latter service presents many features of novel character as compared with past practise, and but little information has been released concerning this plant as we planned to advise of achievement rather than expectations.

At this time the American Gas & Electric interconnected system of eight stations (with Philo in service) is 223,000 kw. of prime movers and also high-capacity (10,000-kw. to 100,000-kw.) interconnections with seven other power systems with 1,297,000 kw. of generators. The generating equipment that may operate in parallel is 1,500,000 kw. Completion of line construction will double these values during 1926. The major system is 132,000-volt transmission for the planned service belt of approximately 700 mi. extending from the southern part of Lake Michigan to southwestern Virginia, and to the Pennsylvania line. Philo, about 10 mi. south of Zanesville, Ohio, is located central to this activity and at the western edge of the southeastern Ohio coal fields. With an abundance of fuel and base load obtainable for the plant, the limitation of development of the site proves to be condensing water from the Muskingum River. Using a 10-ft. difference in water level created by a Government navigation dam at the plant site, it has been possible to take water from above the dam through the condensers and discharge into the lower pool without operating circulating pumps during periods of normal river flow, or probably eight months in the year.

A steam pressure of 550 lb. at the turbines with 725 deg. fahr. temperature, this steam in turn to be withdrawn from the turbine at 150 lb. pressure and reheated to 725 deg. fahr. and returned to the turbine, was selected as being the most advanced practise manufacturers and engineers would endorse in 1922, when construction started; this to result in the minimum of heat loss to condenser cooling water per kilowatt of installed capacity; that is, the maximum conservation of the supply of condenser cooling water. This measure has resulted in ability to install one-third more generating capacity on the plant site than if the lower pressures and temperatures of current practise had been utilized for the apparatus.

The local coal fields under certain seasonal market conditions have large quantities of screenings for disposal at advantageous prices, but such coal fires in a few weeks if stored over 10 ft. deep. As a large yardage of fill was required for plant trackage and the high-tension switchyards to raise the elevations above high-water level of record, this fill material was excavated at one point and the basin formed arranged for an under-water coal storage. This, together with dry coal-storage facilities, enables the successful storage of a six-month's supply of coal at the plant site for the estimated ultimate development of around 300,000 kw. of capacity. Coal can be received and handled at the rate of 500 tons per hour by the belt-conveyor installation.

Forced-blast chain-grate stokers are employed for these variable lower grade coals averaging 12 per cent to 13 per cent ash; 7 per cent moisture; 4 per cent sulphur; 10,700 B. t. u. per pound. There is approximately 1 per cent loss of coal in the ash. Ashes are sluiced to gathering tanks and from there are pumped by dredge pumps for fill purposes about the plant property which will accommodate this disposal for a great many years in the future.

The boilers arranged for 650-lb. maximum steam pressure and 750 deg. fahr. temperature have operated well and no difficulties have been encountered incident to the steam pressures or temperatures maintained. The super-heated and saturated pop valves have operated in a uniformly successful manner a great many times without subsequent leakage at the seats, and we observe no difference in the functioning or probable maintenance of these parts as contrasted with our experience at lower steam pressures. At 248 per cent boiler rating the gas temperatures at the boiler outlet of 582 deg. fahr. is reduced through the economizers to 336 deg. fahr., and on the four boilers equipped with air preheaters is further reduced to a stack temperature of approximately 226 deg. fahr. The valves and high-pressure piping of seamless tubing with Sargol-welded flange joints have in service shown no difficulties worthy of mention.

Water for boiler feed is given initial preparation by sod-ash-and-lime cold-batch treatment, then passed to multiple-effect evaporators using steam extracted from the turbines, or exhaust from the boiler-feed pumps. All water supplied to the boilers is given further treatment of deaeration. Thus far a modest amount of blowing down the boilers, once every two weeks, has proved adequate. The present make-up demand is about 3 per cent for all losses.

The first of our reheat boilers, (one for each turbine unit) has been in service six weeks, reheating the steam withdrawn from the turbine to 700 deg. to 750 deg. fahr. This equipment consists of half of the tube surface of one of the standard boilers, above which is placed the reheating surface for the turbine steam. This equipment is stokered in the same way as the other boilers and without any particular difficulty. The firemen operating this equipment control the boiler by observation of the discharge temperature of the steam from the reheat section in much the same manner as observing a steam gage on a single boiler. Should operating contingencies occur, such as a wide variation in load, with corresponding changes in circulation through the reheater element, measures for immediately checking air blast and coal feed and reducing the induced-draft-fan speed to its lowest running point can be quickly taken and at the same time motor-operated doors in the reheater part of the setting may be opened to admit cooling air. This functions automatically should the turbine under load be tripped out for any reason, and at the same time the valve providing reheated steam to the turbine closes. During operation a number of varied operating contingencies have occurred and the facilities of control in meeting the emergency have functioned well. In all instances the above measures maintained the reheated steam temperature fluctuation within 5 per cent or 10 per cent of the established value before the contingency arose.

Our 40,000-kw. No. 2 turbine unit was first placed in commercial service October 14, 1924, and No. 1 unit, February 24, of this year. The first reheat boiler was completed and placed in service on No. 1 unit March 3, the second reheat boiler is now completed and going into service. The elapsed time to April 1, since starting the turbines is 4800 hours, approximately six months' service time, during which the turbines have operated 85 per cent of the period; for 2½ per cent of the time they were available but not operated for other causes; and for 12½ per cent of the time were idle for adjustments and inspection. During the period 90,000,000 kw-hr. have been produced. The turbines operate smoothly regardless of load, pressure, temperature, reheat and no-reheat conditions.

As yet there has been no opportunity to make tests for apparatus economy in accordance with accepted codes for practise; however, the complement of station meters of various character is quite complete, and to the best of our knowledge and belief, at full load of 40,000 kw. without steam extraction the water rate of the turbine is 8 lb. per kw-hr. with supplied steam at 550 lb. gage, 725 deg. fahr. and reheated to 725 deg. fahr. exhausting against 1-in. back pressure. The improvement with reheat is about 12½ per cent which involves the addition of approximately 8 per cent more heat in the steam as against operating without reheat. We find the heat input to the turbine unit per kilowatt an unusually flat curve over a wide range. With temperatures and pressure conditions of supply maintained constant and reheating temperature maintained constant, at 40,000 kw., taking the value as 100 per cent; at 30,000 kw., the heat-input value is increased ½ per cent per kw.; at 20,000 kw. 3½ per cent, and at 10,000 kw. 15½ per cent, all above full-load value. The pressure at which reheating is done in this cycle varies from 50 lb. at 10,000 kw. to 155 lb. at 40,000 kw. The

pressure drop or loss in withdrawing steam from the turbine, reheating it and return to the turbine is approximately 5 lb. at full-load conditions. This performance is indicative that for the combination at Philo, reheating the steam is a desirable operating condition from quarter load to full load. There is no difficulty in operating the reheating boiler in this range. Further, the arrangement has merit in meeting load conditions of variable character or lower load factor other than at Philo.

All switching at voltages in excess of 2300 volts is done in outdoor yards. The transformers to supply auxiliary service from the 11,000-volt leads of the turbine are located outdoors. All auxiliaries are motor-driven except two spare turbine-driven boiler-feed pumps. No house turbines are used, reliance being placed in the auxiliary transformer for each turbine with a common spare, and in the four outgoing high-tension lines each serving a different section, to provide power for restoring service in the event of a total shut down. Aside from serving the auxiliary transformers, the generator leads go direct to the raising transformers located in the outdoor yard and paralleling of generators and switching to outgoing transmission lines is conducted on 132,000-volt outdoor equipment, service from the plant being at this one voltage. All motor drives for auxiliary and general purposes about the property are arranged to start at full voltage without compensators wherever such equipment can be employed.

The end of the main turbine room accommodates a fully equipped repair shop for mechanical and electrical equipment. Storage facilities and headquarters for personnel are grouped at points of maximum accessibility and minimum movement of individual or material.

The overall performance of the plant may naturally be expected to improve as construction activities are finally brought to a close and the operating conditions and apparatus are tuned up. As typical of the present situation, for the week ending April 4, with 90 per cent load factor and average turbine load of 33,600 kw., the plant produced a net kilowatt-hour for 14,500 B. t. u., including transformer losses to the 132,000-volt feeders. Auxiliary uses were 4.15 per cent of generated value. As regards capital costs, we believe we have expended between $5 and $10 more per kilowatt of installed capacity than if we had constructed the plant according to current lower steam pressure and temperature practise.

In conclusion, this plan from the outset has functioned with equal or less attendant difficulty than our experience with other work in recent years at lower steam pressure conditions. Our Twin Branch plant, located in the vicinity of South Bend, Indiana, which is a duplicate of Philo apparatus, is now nearing completion and likewise placed its initial equipment in successful service with no particular difficulty on April 2.

E. L. Hopping: A brief description of some high points in the design of the latest plant in the system of the Philadelphia Electric Company may be helpful in making studies and decisions for future power stations. It must be remembered that while our decisions have differed from those reached by some other companies, the differences are caused by the different conditions that we had to meet. Each plant must be studied as an individual problem.

Richmond Station is one of four large generating stations supplying current to the Philadelphia Electric Company system and is located in the northern section of its territory, on the Delaware River. This makes the third plant located on the same river, the most southern one being at Chester, about 20 miles distant.

The location of the plant was determined largely from load studies, although the available supply of condensing water and the ability to handle large amounts of coal readily were given due consideration. In the winter, there is a considerable possibility of difficulty in handling coal, due to ice conditions on the river, and, as practically all of the coal used in the Philadelphia Electric Company system is received by barge, the ability to place coal at the plant must be considered very carefully. Just north of the plant, the river conditions are such that ice jams become very serious, whereas, south of the plant, or in the direction from which coal must be obtained, the river is nearly always open.

The ultimate capacity of Richmond Station is to be 600,000 kw. made up of twelve 50,000-kw. units. The station is not yet in operation. We expect to have the first two machines operating by the end of this year.

One unique feature in the design is the separation of the plant into three distinct sections, each section housing 200,000 kw. This arrangement gives a certain amount of reliability which, it was felt, could not be obtained if all of the units were in a single building. A break in the steam line in a modern boiler plant having high pressures and temperatures would very quickly cause a complete shut-down, whereas with the plant divided into sections, a break would affect only the section in which it occurred. Dividing the plant into sections also somewhat increases the light and ventilation.

There are some points of similarity between the design of Trenton Channel plant and the Richmond Station, although in some there is a radical difference. It may be of interest briefly to discuss these points.

The use of pulverized fuel versus stokers was carefully considered and the stoker firing was finally adopted. Studies indicated that, with the use of preheated air, and adding together all of the capital charges, operating and maintenance expenses the cost of energy at the bus would be at least as low as with pulverized fuel. We believe it will be slightly better.

Three other factors also had bearing on the decision. First, the available coal in this territory is of a very high grade and a poorer grade of coal, while costing less per ton at the mine, would cost more per kw-hr. because of the added transportation expenses required to deliver an equivalent B. t. u. value to the plant. Second, the question of ash elimination as Richmond Station is located in a thickly populated district, it was impossible to consider any system where ash or cinders could possibly be distributed on the surrounding territory. The ash problem in pulverized-fuel installations had not, at the time the plant was designed, reached a point where positive assurance could be obtained of its satisfactory solution. Third, the necessity of a large coal-preparation plant, such as the one at Trenton Channel, was considered an added complication to plant operation, as well as adding largely to the capital cost.

The single-ended Stirling type of boiler was used in Chester and Delaware Stations, and has been adopted for Richmond largely because of the success encountered in the operation of the other plants. In stoker firing, the single-ended boiler lends itself to a more convenient method of operation, reducing the number of firing aisles and overhead bunkers required. With the use of economizers which in this case are two-drum, vertical-tube, and a tubular-type preheater, the double-ended boiler could not have been used.

Studies of pressure and temperature made for Richmond Station seem to coincide very closely with the results obtained by the Detroit Edison Company. These indicated that, after considering all of the elements, such as cost, reliability and materials available, the most economical pressure and temperature were around 400 lb. and 700 deg. fahr. The pressure adopted at Richmond Station is 375 lb. at the turbine throttle, with an average temperature of 675 deg. fahr.

Single-shaft tandem-compound 50,000-kw. turbines, running at 1800 r. p. m., were selected because of the simplicity of the entire arrangement. With this type of unit, there is only one generator to handle, and a smaller number of bearings than would be the case in cross-compound machines. The electrical connections are somewhat simpler and the basement illumination and visibility obtainable with a single-shaft unit are greater than with cross-compound units. The capacity of the unit was de-

cided largely on the basis of its relation to the entire system load and the size of the plant.

With circulating water having a temperature variation of from 32 deg. to 85 deg. fahr., careful studies indicated that the lowest yearly cost, after considering carrying charges and operating expenses, justified the use of larger condensers of the two-pass design.

The feed-water heating system employed at Trenton Channel is very similar to the design for Richmond Station. The principal difference is in the arrangement of the condensate and boiler feed pumps. In Richmond Station, the condensate pump is operated in the usual manner, taking the condensate directly from the hot well and pumping it through the eighteenth-stage bleeder heater; then through the deaerator-heater condenser and liquid heater into the deaerator proper. The deaerator chamber acts as a reservoir through which the supply to the boiler feed pumps is maintained.

The high and low water level controls are operated from the water level in the deaerator so that if there is more water available than is demanded by the boilers, a valve is opened, which allows the water to pass to a surge tank. In case there is not sufficient water available for the feed pumps, another valve is opened, admitting make-up water into the deaerator. From the boiler feed pump, the water is passed at high pressure through the evaporator condenser to the twelfth-stage heater. The vapor for the heater deaerator is obtained from the fifteenth stage.

It was felt that having a separate drive for both condensate and boiler feed pumps allowed for somewhat more flexibility and possibly reliability of the entire system than would be the case with a single drive. At Richmond, the condensate and boiler feed pumps are both driven by a. c. 2400-volt motors, the condensate pump having a constant-speed motor and the boiler feed pump, a variable-speed motor. In the boiler feed system there are three pumps provided for each 50,000-kw. unit, one of which is turbine driven. This pump is for use only in emergency or in case of loss of current to the motor-driven pumps. The pump is arranged to come on the line automatically in case the pressure of the discharge nozzle on either or both of the motor-driven pumps drops below a predetermined point.

The decision to use a-c. rather than d-c. drive for auxiliary motors was based on the comparative cost of the two systems and the fact that with the d-c. drive, 500 volts would be the maximum available, whereas with a-c. drive, 2400 volts can be used in practically all cases.

A good many of the motors are constant-speed and wherever variable speed is required, they are within the limits available for variable speed a-c. motors. The only d-c. drive used in Richmond Station is for the stoker motors. On these motors a very close regulation over a wide range is desirable and the power required in this case did not greatly exceed the requirements for emergency service for excitation, et cetera. This allowed the use of an emergency system for the stoker drives.

All of the auxiliary power, with the exception of that required for those known as "essential" auxiliaries, is obtained from the main station bus.

Each 50,000 kw. unit has its own auxiliary bus obtaining its power through a transformer which is tied in solidly to the generator leads and through an oil switch to the unit auxiliary bus. This bus operates at 2400 volts and has additional ties to the 2400-volt station power bus and to an emergency house generator. The house generator is a 2500-kw. turbine-driven unit which is used only in emergency. The unit is so designed that it can come from a cold condition to full speed ready to receive load, in about fifteen seconds. It is arranged to be placed on the line by means of a push button from remote points. The exhaust from the turbine is piped directly to atmosphere, so that no complications would be encountered in opening or closing valves.

The use of a closed system of ventilation for the generators was decided upon after a careful investigation had indicated that the system could be installed at a somewhat lower cost, and that the generator would be kept in a cleaner condition.

The return of the heat from the circulating water in this system was rejected because of the complications involved in maintaining a constant supply of circulating water while the turbo-generator is operating with fluctuating loads. During the summer months, condensate water is too warm to allow for its use and at this period the heat must be discarded in any case.

A more complete description of the size of the units and the arrangement of the plant can be secured by reference to an article on this station which will appear in an early issue of *Electric Light and Power*.

H. R. Woodrow: The Brooklyn Edison generating plants are laid out for a different method of operation from that discussed by Mr. Hirshfeld. The three generating plants are operating continuously in parallel with heavy tie lines between stations. One of these stations is 25-cycle and the other two 60-cycle and a 35,000-kv-a. frequency changer ties the 25-cycle station to the 60-cycle system.

The base load of the entire system is carried on the most economical units in the most economical plant which is, at the present time, Hudson Avenue Station. It is intended that these stations should hold in step during the major number of troubles and sectionalizing reactors are very generally used to segregate the trouble and limit the value of the short-circuit current.

For a detailed description of the Hudson Avenue plant and system connections of the Brooklyn Edison Company, I would refer to the April 1925 issue of the *Electric Journal*.

In all cases second-line defenses are provided in the form of automatic switches segregating certain groups of feeders in case of the main feeder switch failing to operate and each feeder is provided with reactors and reactors are installed between sections to maintain voltage for high continuity of service under disturbance conditions.

The auxiliaries in the power house are all electrically driven with the exception of reserve boiler feed pumps and all auxiliaries are provided in duplicate for the so-called essential duties, each half of which is supplied from different sources although tied together through reactors.

F. A. Scheffler: I want to compliment Mr. Alex Dow on his wonderful "sticktoitiveness," you might say, in adhering to the design of the type W Boiler that he selected about fifteen or twenty years ago to use in the Delray plant of the Detroit Edison Company.

I had the opportunity and great pleasure of working out that design of boiler with Mr. Dow, and the results were eminently satisfactory in producing a type of boiler at that time which was four times the size of any other boiler in the country. I think Mr. Dow deserves a great deal of credit for introducing, in this country, the large unit type of boiler for public-service stations.

He has continued to use that type in all of his other plants, and, today, I believe they have thirty-five to forty boilers of that type operating at from 300 per cent to 400 per cent of rating on peaks.

H. W. Brooks: Many writers on combustion in the past have stressed the importance of turbulent flow, agitation and mixing in pulverized-fuel furnaces as an aid to the natural diffusivity of the burning gases upon which speed of combustion, length of flame travel and hence combustion volume depends. A practical means of accomplishing this mixing has heretofore remained undiscovered.

Several years ago it occurred to one of the engineers of the Fuller-Lehigh Company that one of the most intense manifestations in Nature of turbulent flow and agitation of gases and particles in suspension was in the tornado, where it had been repeatedly demonstrated that materials of considerable tensile strength had actually been torn apart, disintegrated and reduced to fine pieces

and sometimes to powder by the intense centrifugal action of the air. Experiments were started at Fullerton on a small furnace 18 in. square by 3 ft. deep in which the jets were placed to throw the flame tangent to a tornado of fire within the furnace, the flame of the first jet being deflected before it reached the refractory walls by the impingement with equal velocity at right angles of the flame from the second jet, the third jet again changing the direction 90 degrees, and the fourth jet completing the tornado within the pot. Fig. 1 shows in plan, the application both to the circular and the square-pot furnaces.

It was well known that the external walls of the tornado of nature had been observed to be rather sharply defined from the surrounding air. Thus it was decided to adapt this principle by placing the pulverized fuel jets in such relation to the refractory walls that there was little, if any, impingement of the fuel tornado on the furnace walls. As was anticipated, therefore, the refractory walls showed little damage due to erosion, and thermocouple temperatures taken on the inner refractory surface of the furnace showed that the inner face of the brick never exceeded 2700 to 2900 deg. fahr.

It has also long been recognized that the transmission of sensible heat from the hot gases from the furnace through the tubes of the boilers to the water on the other side was limited by the existence at the boundary surface of a "dead film," generally assumed to be about 1/40 in. in thickness, of relatively cool gas in which convection currents apparently did not take

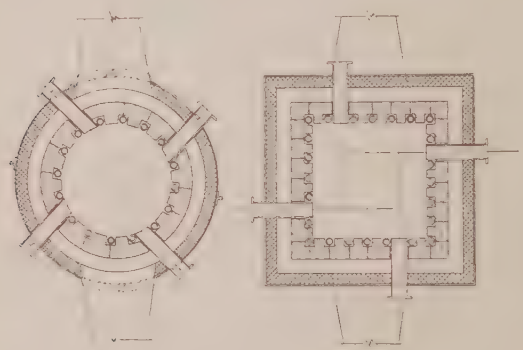

Fig. 1

place, and which owing to its low conductivity offered a high resistance to the passageof heat (other than radiant) through it. This "dead film" is the main and most potent obstacle to rapid heat transmission in the boiler, and it follows that its complete or even partial destruction will greatly assist the flow of heat and hence the efficiency of the boiler. Prof. J. T. Nicolson of the Manchester School of Technology demonstrated a formula proving that the heat transfer was a direct function of the velocity of molecular travel of gases passing the tubes. Thus it was anticipated and tests subsequently proved that with the higher scouring action of the swirling gases in meeting the boiler tubes there would not only be a higher rate of heat transfer and higher boiler efficiency, but also a cleansing action which would keep the tubes clear of deposited ash.

Early during the experiments the nature of the ignition and combustion taking place in the well, proved quite unlike anything experienced pulverized-fuel engineers had hitherto seen in powdered-coal combustion. The flame itself resembled that of a blow torch, virtually a "ball of fire," combustion apparently taking place in a limited zone within the well. By regulating air admission and air pressure it was possible to move the hottest zone into the well itself or to a point just in front of the well. Appreciating further the gains due to the more efficient transfer of heat by radiant energy as a result of this "ball of fire," the inventor had still further reason to expect efficiencies higher than had been before demonstrated in pulverized-fuel combustion, as well as a flatter overall performance curve at high ratings.

These experiments were kept secret for several years, until finally a few of the larger operators were shown the experimental furnace at Fullerton. Several immediately volunteered to install a furnace of the new type, but the results which indicaten heat releases many times greater per cubic feet of combustiod volume than had ever been accomplished before were so revolutionary in character that the company felt it best to withhold a commercial-scale installation until they had finally and thoroughly convinced themselves that no practical operating difficulties would intervene.

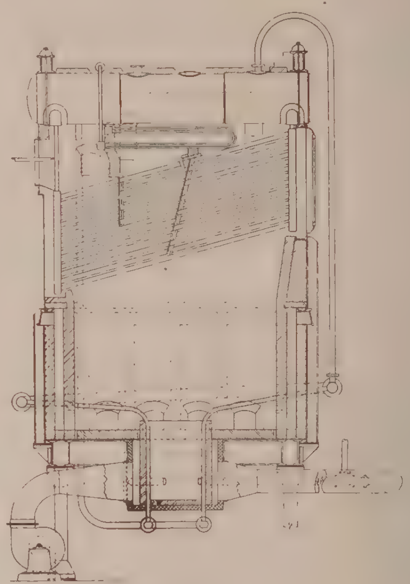

Fig. 2

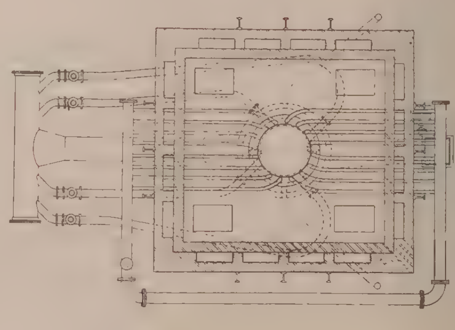

Fig. 3

Finally on February 5, 1924 an agreement was entered into with the United Electric Light and Power Company of New York City by which a commercial-scale experimental installation of the new furnace would be made at their Sherman Creek Station alongside five other boilers fired by the older pulverized-fuel firing methods.

The operating company expressed the desire to make the tests entirely with their own personnel. Today it is understood these tests have been completed. Although full details cannot be made public we are permitted to state that the efficiencies have actually proved approximately 3 per cent higher than with any other method of firing, and the curve of efficiencies at various ratings has been much flatter than anything heretofore demonstrated.

Fig. 2 shows one of the more recent applications of this furnace. It will be noted that above the well there is provided a dispersion chamber in which the hot gases after burning are allowed to expand before reaching the boiler tubes, thus reducing the tornado effect to a value which can cause no possible erosive effect on the boiler tubes. The theory of this chamber is to allow just sufficient velocity to scour off the "dead film" from the boiler tubes without going any further in attacking the tubes themselves. It is not possible to state at this time the minimum size to which this chamber may eventually be reduced. It has definitely been established, however, that the combined volume of well and dispersion chamber can be made substantially less than the combustion space provided in the old-fashioned stoker setting. Knowing that we can convert present stoker-fired settings by this means, and attain the highest boiler ratings, we have at this time no occasion to go further until the application is extended to other services, such as transportation and marine. Fig. 3 shows a plan of the water-cooled well as actually applied on the later designs.

Simultaneous with the tests at New York, research has been continued at Fullerton on a furnace consisting of an 8-ft. cube. In this furnace the coal equivalent of a 1500-h. p. boiler at 632 per cent of rating has been burned in the volume of an 8-ft. cube.

It is felt that the "well-type" furnace is a demonstrated success and that for the first time in the history of pulverized coal the problem of turbulent flow and hence the problem of combustion volume has been solved. Not only may pulverized coal be efficiently burned in combustion volumes as small as those previously employed for stokers but actually smaller furnaces may be installed where necessary. For the first time, completely successful application of pulverized coal to transportation and marine service becomes possible, as does also the conversion of present stoker-fired furnaces to the advantages of pulverized coal without the necessity in many cases of more than slightly modifying the present furnace construction.

H. R. Summerhayes: The voltage selected for the Trenton Channel Station is 120,000, and 132,000-volt apparatus has been used. That, we might say, is commendable conservatism, but as manufacturers, we think it is unnecessarily conservative. We have evidence from experience that the Institute tests are about right. We think the equipment would stand 132 kv. and if it is to be used at 120 kv. it would seem to us unnecessary to have so large a factor of safety. On the Western Coast, we have used for 220-kv. circuits apparatus designed for high-potential tests corresponding to 187 kv., which has given good service.

The next point that I want to comment on is along the lines Mr. Woodrow mentioned, namely, that the plants of Detroit system are tied together rather loosely, with weak linkage, whereas, it is the practise in other large systems to tie the plants together rather solidly, using reactors, and I am inclined to think that as the plans of the Detroit Company progress they may find it advantageous to have a tighter linkage and links capable of transferring more power.

The other point is the old question of direct-current auxiliaries and I suppose that will never be settled. It appears that means of obtaining direct current, perhaps, cost more and auxiliary motors may cost more, but you do obtain very perfect control, and I think that the question has yet to be settled as to whether the perfection of the control obtained is worth the money it costs.

K. M. Irwin: It is brought out in this paper that theDetroit Edison Co. ties its stations together loosely. This must mean that the Delray, Connors Creek and Trenton Channel plants take the loads of their particular districts, and therefore, the load factors of their particular districts. As the Trenton Channel plant does not operate as a base-load plant, but operates on the load factor of its district, it must have been more difficult to justify the cost of equipment than it would have been if this plant had operated on the base of the load, and in that way had a higher load factor and a greater divisor to divide its investment costs.

In the reasons given for the choice of pulverized coal, the statement is made that a reduced number of boilers could be used with pulverized coal than could have been used with a stoker installation. I wonder whether Mr. Hirshfeld has found that the limitations in boiler capacity are in the fuel-burning equipment. With the type of boiler adopted at Trenton Channel, I would believe that the limitation would be found in the boilers and not in the fuel-burning equipment. Tests have been run on a stoker installation in which ratings have been obtained in the neighborhood of 500 per cent without serious falling-off in efficiency. I do not believe that these ratings could be exceeded in Detroit even with pulverized coal.

In the list of motors, the 2000-kw. house-generator sets have their auxiliaries a-c. driven, and the 4000-kw. d-c. house sets have their auxiliaries d-c. driven. It would be interesting to know the reasons for the changes of the current for the auxiliaries on these house sets.

Louis Elliott: The recent putting into operation of the Philo and Crawford Avenue stations, with the low fuel consumption reported, makes of particular interest a decision such as that made for Trenton Channel,—to install 375-lb. turbines working on the regenerative cycle, as against a higher pressure plant designed for reheat.

A recent estimate for a moderate-sized station indicated an excess cost for a 650/550-lb. reheat plant, as compared with 425/375-lb. of about 7 per cent. With a capacity factor of 60 per cent annual, this additional investment would entail an increased fixed charge around 0.3 mills per kw-hr. If it be assumeP that the 550-lb. station would permit a saving in production cost equivalent to 10 per cent of the fuel cost, this saving with 10,000 B. t. u. coal at about 1.1 mills per lb. in the pulverized bins would amount to between 0.15 and 0.2 mills per kw-hr. output.

For this situation therefore the recommendation was made that 425-lb. boilers be installed, with turbines good for 375 to 400 lb. at the throttle. On the above basis coal would have to cost nearly double its present price in order to give an equivalent cost of energy for the two pressures. Different assumptions as to load factor, coal cost, or other factors would of course modify the result. In general an expensive high-efficiency installation should justify itself for the first few years of operation, for as the years go on the reduction in load factor will tend to counterbalance any increase in fuel cost.

Aside from the estimated saving in combined fixed and production cost of energy, the lower-pressure equipment is more thoroughly developed and therefore probably more reliable, and the 375-lb. regenerative-cycle plant would be simpler to operate than the 550-lb. reheat station. The 375-lb. pressure is now standard, and it is uncertain as to what the next higher standard will become,—whether 550, 750 or higher. It is believed that in general there should be a considerable saving assured before newly developed equipment and designs are adopted.

It would be of great interest if the author would give the expected economy in B. t. u. per kw-hr. output,—with fuel available and with load factor as anticipated. A statement also as to any estimate of comparative plant cost for the pressure adopted as against a 550-lb. reheat plant, and the estimated comparative economies would be of great value.

C. F. Hirshfeld: When I spoke of pulverized fuel as being advantageous in that it would enable us to take advantage of variable qualities of coal, I did not mean that we could use West Virginia coal one day and Illinois coal the next day. Buying as carefully as we know how with men who live in the coal fields, it is impossible for us to bring to Detroit one grade of coal.

Some of the coal we get is poorer than the rest. Our stoker-fired plants in the past have proven very touchy with respect to the grade supplied. If we can get the grade of coal for which the plant was designed, it does very nicely. If we get a greater quantity of ash, we lose both in capacity and efficiency,

and it was in that respect that we had considered variable qualities of coal in making this decision.

Improvements in the manufacture of stokers since the time this decision was made (which is several years ago) have greatly extended the capabilities of the stoker in this direction. At least, some varieties of stoker are not now limited to the same extent as they then were.

In connection with the use of d-c. auxiliaries, I stated quite flatly that it was a case of personal prejudice on the part of the engineers responsible for the designing of this plant.

It may be of interest to you to know that the cost of obtaining our d-c. auxiliary power, with the separately driven d-c. generators, is practically the same as though we took a-c. power from our main units and converted it. There is, however, an advantage in our d-c. power supply not being tied to the operation or performance of our main units. We admit that our investment charges are higher but we prefer our system nevertheless.

With respect to Mr. Sheffler's comment on boilers, we now have forty-four, varying in size from 1250 h. p. to approximately 3000 h. p. boilers. He was not correct in his statement regarding the ratings at which those boilers are operated. The old stoker-fired boilers reached limitations at about 200 per cent in some cases and 250 per cent in others. The boilers at Trenton Channel Station, which are pulverized-fuel-fired have been driven to about 350 per cent of rating. In no case in which the double-ended or Type W boiler was used has the limit been found in the boiler.

Referring to Mr. Erwin's discussion, the matter is something like this: There is no question but that you could get a stoker to give ratings equally as high or higher than obtained in Trenton Channel Station. Parenthetically, it is also true that we could drive the ratings at Trenton Channel very much higher than those obtained. As we saw the problem at the time we designed this plant, the rating to which a stoker-fired boiler could be driven was dependent only upon the grate area or the area of the stoker and the ability to maintain the furnace wall.

However, we do not believe and we have not yet seen any proof that a stoker can be built which is capable of driving a boiler to ratings in the neighborhood of 400 per cent or higher, which will give a reasonably high efficiency at those ratings and maintain a reasonable efficiency at very much lower ratings. In other words, you sacrifice considerably in what you might call the combination of flexibility and efficiency when you attempt to get a stoker-fired equipment to carry over a wide range of rating. I do not know if the stoker manufacturer is going to be able to remove that limitation or not. So far as I have been able to obtain proof he has not yet done so.

Mr. Elliott asked about the performance of this station. The station was designed to give a net kilowatt hour, that is a kilowatt hour of output, for about 16,000 B. t. u. when operating with an annual load factor of the order of 50 per cent. The station has now been in operation, in one way or another, for something over six months, possibly eight months, and the performance has been improving monthly. Some weekly figures have already dropped below 16,000 B. t. u., the value which we assumed when we designed the station. We are not able to say whether those figures are correct, but the figures that we are willing to give you hit close to the 16,000 B. t. u., which was the design point and we may do better.

The cost of preparing pulverized coal is always one of the contentious points. I have here the figures for three months, January, February and March, the March figures being incomplete. In these figures, we have included every item of operating cost for coal handling and preparation from the time when the coal finds itself in the track hopper and until it finds itself in the pulverized-fuel bunker, ready to be fired into the boiler furnace. We have included all labor costs, both operating and maintenance. We have included all power, we have included all steam, both the steam used in drying the coal and the steam used for heating the preparation house and you will notice that this was during the two severe months of the year. We have included all operating material and all maintenance material. The figure runs at approximately 30 c., pulverized, during January and February. In January, it was 29.14c. In February, it was 30.36c.—the increase in February being due to the fact that maintenance was quite a bit heavier in that month than the preceding month.

To make these figures of real significance, I should say this: They are obtained from a plant which is using small pulverizing mills, nominally six-ton mills. They are obtained on a preparation house which is designed to handle exactly twice the amount of material that is now being handled. The labor used will be the same when handling twice the material as it is now. The maintenance will, of course, go up. As near as we can estimate, if this plant were used to capacity and all the charges were made as they have been outlined, the figure for preparation would be a little under 22c. per ton. In charging steam and in charging power in these figures, we have used cost of steam and cost of power as actually shown on our books for steam sent out from the boiler room to the turbine room, and for power sent out over the lines to our customers, so that we haven't either overloaded or under-loaded those items.

With respect to Mr. Woodrow's and Mr. Hays' discussions, in which they refer to our, let us say, loosely linked system, I believe that we may ultimately come to a more tightly linked system. We have followed the other method principally for three reasons. In the first place, it fitted our conditions ideally. In the second place, we were fairly sure that it would work, and experience has shown that it does work moderately well. Third, we did not like to contemplate the cost of reactors and places in which to place them and all the trimmings that go with them.

I believe it was Mr. Erwin who worked around from that loosely linked system to the conclusion that our Trenton Channel plant, which is our most efficient, could not be used to the best advantage. To a certain extent, that is true, but only to a very limited extent. Immediately adjacent the Connors Plant and the Delray Plant there is sufficient load to load the plant properly. Trenton Channel can obtain quite enough load to operate as near base load conditions as we care to approach by supplying the so-called down-river industrial load, that part of the industrial load that it can pick off from the Western side of the City of Detroit; such load, very largely industrial, which can be obtained in the outlying district, combined with such industrial load as can be obtained through feeding back into the city from the 120-kv. bus or trunk referred to in the paper. So our loose linkage has very little effect on our efficiency. On the other hand, it is not the policy of our company to load up its new plants at the expense of its older plants. It pays us, or at least it has paid us in the past to go a certain distance in that direction, but not as great a distance as has been proven advisable in other cases.

As Mr. Brooks was describing his new furnace, it passed through my mind that if one could use a small furnace but had to add to it a large mixing chamber, it did not make a lot of difference since you ultimately used the same number of cubic feet as you do with the older designs. I can't see that there is much choice. Mr. Brooks rather implied that one could do away with that mixing chamber if forced to do so, but I am wondering if that furnace were brought too close to the boiler tubes, whether you would not carry up so much fused ash as to put the equipment out of commission very quickly. I do not believe the manufacturer has had sufficient experience with the device to be able to answer that question. I followed the tests at Sherman Creek very closely, but they were not planned in such a way that that question could be answered by them.

Mr. Woodrow's discussion reverts to tight linkage as against loose linkage. He refers to safety devices intended to function serially. No matter how you plan you may never be sure

that this thing or that thing will really work. On that account we have preferred to cut out all such trimmings and limit ourselves to loose ties which would break loose or burn themselves up.

Mr. Erwin asked me why we used a-c. auxiliaries on the a-c. house-service machines. That is due to another one of our "hobbies." If we have steam, we can start the a-c. machine and with the a-c. machine we can start everything else. We felt that if we faced a situation in which we wanted to start that little house-service unit in a hurry, we wanted to start with the minimum of manipulation. The a-c. driven auxiliaries are so connected that they come up with the machine and we feel that this is the simplest starting scheme we could get. That is why we used the a-c. driven auxiliaries with the a-c. house-service units. It is not the first time we have used that scheme and it has worked very well in all cases so far.

With respect to de-aeration, we have used in this plant steel-tube converters. The natural conclusion would be that we should be very careful not to have any more than the minimum feasible oxygen content in the water. Our experience in Detroit has been that our water is of such a character that we can stand more oxygen than is commonly given as the maximum limit consistent with reasonable life of steel tubes. Our experience with steel tubes at the old Delray plants leads us to believe what I have stated.

The system at Trenton is built so that there is a surge tank. The surge tank is arranged so that it can be sealed with steam if necessary, but it is not so sealed now. The water passes into the condensers where it is reasonably well deaerated, although we have not provided separate deareateing devices. It is too early to say whether this system works or not. Four or five years hence we will be able to tell if it doesn't work.

With respect to the pressure on the suction of the boiler-feed pumps; when we purchased these pumps, we had all the characteristic curves modified until we got what appeared to be a combined pump unit, which would be safe against flashing at the boiler-feed pump suction. Up to date, we have had no trouble from that source. We have had a little trouble due to hammering of the hot-well pump. The reason for that is that the pump does not have a sufficient head of water above it. We are now attempting to rectify that and expect to succeed in doing so.

FREQUENCY MULTIPLICATION[1]

(Lindenblad and Brown)

St. Louis, Mo., April 15, 1925

E. W. Kellogg: Mr. Brown spoke of getting a wave of 500 cycles and make it into a 1000-cycle wave with 90 per cent efficiency. The story is not complete until we know just what it does to the efficiency of the generator supplying the original wave.

W. Rogers: I should like to ask what use has been made of this principle in multiplying the ordinary ringing frequency which is 16 cycles to 133 cycles for use on composite ringers on telephone circuits.

S. P. Shackleton: I think the answer is that there has been no practical use made of it, and the principal reason is, I believe, that the frequencies are so low that, to get very great efficiency it would require apparatus which would cost more than other apparatus available for generating 133 cycles.

For quite a number of years we did use the fundamental ringing frequency of 16 cycles or 20 cycles, whichever it happened to be, to operate an interrupter to produce the higher frequency That, however, was none too efficient, and recently that has been superseded almost entirely either by a motor-generator set or by an improved type of interrupter operating from direct current.

W. Rogers: I do not suppose that this is a matter of much importance to the telephone companies, but it is of some importance to the railroads. The telephone company is in a position to use the methods described by Mr. Shackleton, because of their larger installations and because of the fact that their long-distance circuits are numerous and centralized. However, on the railroad, we have composite circuits which terminate at points where these things are not available. One of our greatest troubles is with our composite ringers. Most of us are still using the old interrupter, operated from d-c. or 16-cycle ringing current, and it has been suggested, and I believe demonstrated, that it is possible to take two, or, perhaps, three 47A repeating coils and, by saturating the cores of one of them and connecting them in a certain manner, change 16-cycle ringing current to approximately 133 cycles.

S. P. Shackleton: The only case of which I know where the higher frequency, 133 cycles, has been obtained by frequency changers of that type has been in Philadelphia, where our men became very much interested in that problem. They had working for several years, composite ringers supplied by means of such a device. I looked over the layout there and I do not remember all the details of it, but I am very sure that if the frequency changer was made commercially available it would cost more than the interrupter which we are now using on our telephone circuits.

W. W. Brown: In reply to Mr. Kellogg's question regarding the efficiency of the power supply for frequency multipliers load: It is possible to adjust the frequency-multiplier circuits so that the load is approximately at unity power factor. This is entirely feasible in radio-frequency circuits, but uneconomical in relatively low-frequency circuits on account of the large kv-a. of the condensers required. Multiphase power supply appears to be the solution for the relatively low-frequency circuits.

Another probable radio application of frequency multipliers will be in connection with necessary changes to increase the possible rate of sending by long waves. In order to improve the efficiency of long-wave antennas, the resistance has been decreased to a remarkably low value. The effect of lowering the resistance is to lengthen the time constant of the antenna. A low time constant of such an antenna tends to cause distortion of signals at high rates of sending. By using a higher frequency, the time constant of a given antenna is shortened, which permits higher rates of sending. The application then will be in multiplying the entire output from a large alternator for high-speed transmission.

N. Lindenblad: In answer to Mr. Kellogg's question, the primary source is not affected as feed-back effects are prevented either by means of tuning or the Alexanderson neutralizing transformer.

In answer to Mr. Roger's question, it must be understood that frequencies obtained by the multiplication method referred to are only whole multiples of the fundamental frequency, not fractional multiples.

I agree with Mr. Shackleton regarding the probable high cost of the frequency changer for increasing the frequency of 16 cycles to 133 cycles, unless the demand for such a device is large enough to justify the cost of the development work.

COAL MINE ELECTRIFICATION[1]

(W. C. Adams)

St. Louis, Mo., April 17, 1925

Carl Lee: There are a few examples cited in this paper which might require amplification or qualification for an engineer not familiar with this particular industry. Estimates are made showing returns of 6 to 20 per cent on the investment made on labor and fuel-saving equipment. Yet the cost in some cases runs up to nearly half a million dollars. The ordinary coal company would hardly decide to add so much to its capital investment for a small return. The normal conditions of coal mining are so frequently interrupted by strikes, poor market and

1. A. I. E. E. Journal, Vol. XLIV, May, p. 469.

1. Pamphlet form only.

competition that the smaller the mine investment the nearer the operator can come to breaking even in the long run.

Without discussing the various points in detail, it might be said that this paper emphasizes the fact that in the mining industry, which has been so rapidly electrified, it is important that the electrical engineering problems be given due consideration. To do this certainly requires the services of an engineer who has had experience in that line. Haphazard decisions will likely mean a loss in one way or another, which might be avoided by the analysis and recommendations of a properly qualified engineer.

E. J. Gealy: The only correct basis of deciding whether a coal-mining company should purchase power or generate it is an economic one as presented by Mr. Adams. All phases of the question should be given due consideration.

If a coal company is not prepared to give its own power plant proper consideration and a fair opportunity to operate at best efficiencies, it is surely arguing itself into using purchased power. Often a coal company will do more to help reduce its power bill received from a utility company than it will to help its own power plant to operate economically. A power bill represented by cash to an outside company is always given more thought than costs to operate a mine power plant. Consequently a coal company will often do more to centralize its load, operate with a good load factor and good power factor when purchasing power than when generating its own energy.

At most coal mines, low-grade fuel is available for use in the power plant. This low-grade fuel if loaded, shipped and sold at a remote point often represents a loss. In such cases the coal company using this fuel in its own plant may rightly credit the plant with the amount of this loss rather than charge it for the fuel at its selling price.

Evidence of the fact that a coal-mine power plant can successfully compete with a public utility is found throughout the coal fields. Outstanding examples are the Consolidated Coal Company plant near Staunton, Illinois, which sells power to the town. Another large coal company in Central Pennsylvania has been selling power to a public utility company for years. Such examples indicate quite clearly that the advantages are not all conclusively upon one side or the other. Careful and thorough consideration must be given the question in all cases.

I also know of a company which generates most of its own power but ties in with the power company which carries the peak loads. Thus the load factor upon the coal company's plant is almost unbelievably good. The company has a large pumping load most of which is off in the day and on at night.

Specific examples show that it is quite possible to generate power at or near some coal mines. From the tipple of the No. 12 mine of the O'Gara Coal Company near Harrisburg, Illinois, one can see almost directly under his feet the coal company's power plant and also one of the largest public utility plants in Southern Illinois. Again, in Pennsylvania the Glen Alden Coal Company generates more power than the public utility company in its district.

However, there is another phase of this question to be considered. Many coal companies can effect much larger savings from capital invested in machinery used in the mining and preparation of coal than by owning their own power plant. Obviously a coal company should first consider placing capital where it will effect the largest savings or profits.

Turning to the use of motor-generator sets at coal mines, it will be interesting to note that records obtained early last year show that 73 per cent of the automatic power-converting substation equipments furnished by the large manufacturers was equipped with motor-generator sets.

Where considerable induction-motor load exists the synchronous motor-generator set lends itself admirably for power-factor correction. A large anthracite company is now using a 440-volt synchronous motor on one of its motor-generator sets and correcting power factor right where the poor power factor originates.

W. C. Adams: While an engineer's natural tendency is to put in equipment to secure the greatest efficiencies, sometimes, irrespective of the cost, there is a limit to the amount that should be expended to secure this better operating efficiency which is based on the earnings to be derived by such improvements. There is a difference of opinion of the yield required to warrant an expenditure. I believe that an investment should yield at least 10 per cent, and for conservative estimates, 15 per cent should be used.

There is a tendency and feeling among coal operators—and it is often right—that they should limit their investments in one operation to as low a figure as possible, with the thought that they can secure better returns on their money by other investments which may be operations in another field.

Often available capital is limited and it is necessary to sacrifice some efficiency to secure the essential features necessary for a successful operation.

With such a condition, an expenditure of $500,000 for a power plant might not be warranted, even though it would result in a yield of from 10 to 15 per cent. However, if such a power plant is dispensed with, it should be certain that a reliable source from which to purchase power can be secured.

Irrespective of efficiencies that may be obtained, the amount of capital expenditure warranted for a given operation must be based on all the facts covering possible earnings and return of investment. To secure the correct answer, a careful study and analysis of the existing conditions must be made and the decision must be an economic one.

PURCHASED POWER AS APPLIED TO PLATE GLASS MANUFACTURE[1]

(HARRINGTON)

ST. LOUIS, MO., APRIL 17, 1925

C. W. Fick (communicated after adjournment): Mr. Harrington's very interesting paper may raise the question of why this arrangement of vertical synchronous-motor drive is not universally adopted by the plate-glass manufacturers. There are some twenty plate-glass plants in this country with a total of 100 to 125 grinding and polishing machines. Of this number a majority must operate for a short time at slow speed at the beginning of each operating cycle, due to the method of lowering the grinder and polishing disks onto the glass. Thus, the synchronous motor is eliminated for these cases, unless a frequency changer and double bus arrangement is used.

A wound-rotor induction motor arranged as were the synchronous motors described by Mr. Harrington would have a power factor of between 65 and 68 per cent and would be more costly and require more control equipment.

However, there is no reason why the belts and ropes which are at present used on perhaps 75 per cent of these tables, cannot be eliminated by the use of horizontal slip-ring motors (as new motors are required) of 200 to 250 rev. per min. coupled to the bevel-gear shaft, with a saving of maintenance and power, and in some cases of first cost.

A. L. Harrington: The question has been asked why high-tension lightning arresters have been omitted from this substation. It was our privilege to be connected with a power system having some of the earliest outdoor substations. This system was in a locality subject to lightning any day of the year. Although the original main and substations were equipped with arresters, business increased so rapidly that it came about that transformers (in some cases) were on hand for new customers but no lightning arresters. A comparison was then available between protected and unprotected stations. Such failures as were experienced were never from line to ground but rather from turn to turn or coil to coil in the transformer. Much

1. A. I. E. E. JOURNAL, Vol. XLIV, May, p. 463.

evidence was present to show that the dangerous disturbances were often of low potential but high frequency. In many cases results did not seem to justify the cost of lightning arresters.

With the greatly improved design of some modern transformers, we feel that they do not need the assistance of arresters. Recently these conclusions have been proven true in the Pittsburgh territory, but at a lower voltage than the substation under discussion. It is possible to add arresters to this job later if conditions of actual service seem to warrant them.

SELF-EXCITED SYNCHRONOUS MOTORS[1]

(KOSTKO)

ST. LOUIS, MO., APRIL 14, 1925

H. Weichsel: The self-excited synchronous motor has, during the last few years, forged its way rapidly to the front and promises to take a very important part in the lay-outs and designs of future power plants, distribution systems and consumers' plants.

Mr. Kostko's paper on this type of machine is, therefore, to be welcomed, as it deals with the general theory governing the different machines which belong to this general class of self-excited synchronous motors.

Mr. Kostko has, in an admirable manner, gone to remarkable details in deriving the general locus for the current vector of these machines and in doing so has made full use of the principle of inversion, which is an extremely useful mathematical tool when it is desired to derive the current locus of an electric machine which is connected to a supply of constant potential. It is to be regretted that this method is not more generally known and used, and, therefore, it is to be hoped that Mr. Kostko's elegant application of this principle will help to stimulate the general interest in this method of attack for deriving the current locus of electric machines.

Personally, I have been, for a great number of years, an ardent advocator of graphical methods for the solution of a-c. electrical phenomena and, therefore, welcome heartily Mr. Kostko's method of deriving circle diagrams for this type of machine.

Experience has shown that the circle diagram of a simple induction motor has contributed more than any other factor to the full understanding of the performance and the interaction of the different phenomena which take place in this type of machine. The graphical methods readily give an answer to the behavior of the machine under most any imaginable operating condition.

The induction-motor circle diagram has also largely contributed to the high state of development of the present induction motor. The economic savings which have resulted from the general application of the induction-motor circle diagram must be enormous and no doubt run into millions of dollars.

There are two kinds of circle diagrams for the induction motor; namely, the so-called Heyland or Behrend diagram and the Osanna diagram.

The first-mentioned diagram neglects in the derivation of the current locus the influence of the ohmic resistance. The second-mentioned diagram considers the ohmic resistance and, is, therefore, of particular interest from the theoretical point of view.

The mathematical derivation of the first-mentioned diagram is extremely simple. The contrary is true for the Osanna diagram. Also, the actual construction and application of the Hyland diagram is the simplest possible, while this cannot be said for the Osanna diagram. The additional accuracy obtainable by the use of the more complicated Osanna circle over the extremely simple Heyland circle is small and often even of doubtful value. For this reason, the Heyland circle has found a very wide field of application, while the Osanna circle is used only for special cases.

Another reason for the general preference of the Heyland circle will be found in the fact that both diagrams are based on certain assumptions, such as constant leakage reactance and proportionality between magnetic lines and ampere-turns. It is a well established fact that the assumptions are not completely fulfilled in practical machines. Why, therefore, go into the complication of considering the influence of the ohmic resistance, which, in the majority of cases, produces a very much smaller effect on the current locus than the variable leakage and saturation which is found in nearly every actual machine. The great popularity of the extremely simple Heyland diagram is, therefore, entirely justified. Especially if we consider that by a very slight addition to the Heyland diagram, it is possible to obtain the exact theoretical performance with due consideration of the resistance.

Similar conditions exist in self-excited synchronous motors. The influence of the leakage reactance and especially ohmic drop on the current locus is small.

In actual machines, neither the assumption that proportionality exists between magnetic lines and ampere-turns nor the assumption that the reactance is constant is fulfilled.

In addition to this, there exists a magnetizing effect due to the currents under the brushes which cannot be readily considered in a diagram. The details of this can be seen in the paper I presented before the Midwinter Convention of the A. I. E. E., 1925.[2]

The great complications introduced in the derivations of the circle diagram due to the influence of ohmic resistance, as well as the complications produced thereby in the construction and application of these diagrams may quite possibly prove themselves to be so large in comparison with the available increased accuracy, that the exact diagram will find only a relatively small field of practical application, but it will always be considered as a very important feature from the strictly theoretical point of view. At least, this would be in agreement with the experience of the Osanna circle diagram for induction motors.

On the other hand, a circle diagram for self-excited synchronous motors which neglects such minor effects as ohmic resistance promises to find a wide field of practical application on account of the extreme simplicity of its derivation and construction. Its simplicity, similar to the Heyland diagram, makes it further extraordinarily easy to understand at a glance the influence of the main factors which enter in the design and operation of these motors.

Furthermore, similar to the Heyland diagram, it is possible to derive from this simple diagram by relatively simple means the performance even under cases where it is desired to consider the factors which have been neglected in the derivation of the diagram. For the last few years, I have successfully used in practical design work, such a simplified circle diagram. Its derivation is based on the fact that the resultant field in any a-c. motor must be constant when constant voltage is impressed on its terminals and the influence of the ohmic resistance and reactance is negligible. With this assumption as a basis, it requires about two lines of mathematical formulas to derive the current locus.

Fig. 1, herewith, shows a current locus derived in such a manner for a machine connected in accordance with Fig. 8 of Mr. Kostko's paper. In this particular case, the ordinates of the circle are positive for all load conditions. Therefore, the very interesting result can immediately be seen from this diagram that a machine connected as per Fig. 8 is unable to operate as a synchronous generator as long as the field and armature are in the motoring connection and the direction of rotation for generating and motoring is assumed to be alike.

Many other extremely interesting conclusions can quickly be drawn from such simplified diagrams. For instance, by constructing the diagram for different angles between brush axis and field axis, it will be seen at a glance that under idle running

1. A. I. E. E. JOURNAL, Vol. XLIV, June, p. 604.

2. A New A-c. General-Purpose Motor, H. Weichsel, A. I. E. E. JOURNAL, April 1925, p. 356.

conditions the voltage across brushes is not zero when the brush axis coincides with the field axis and does not reverse when the brush axis is displaced in either direction from the field axis, but follows a law given in full lines in the Fig. 2 herewith and does not follow the dotted lines, as one is inclined to expect. This simplified method of attack lends itself equally well to any kind of self-excited synchronous motor. A further discussion of the details of the general principle and application involved in these simplified diagrams would lead too far on this occasion.

There are a few statements in Mr. Kostko's paper which might lead a casual reader to wrong conclusions and a few words to prevent such pitfalls may be appropriate.

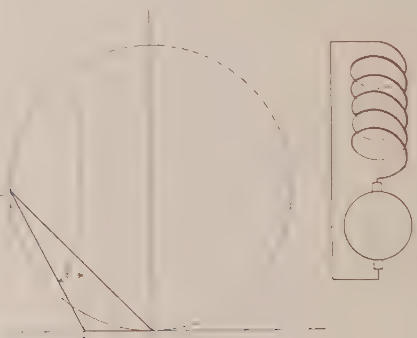

Fig. 1

Mr. Kostko states that any number of coaxial field windings connected to different brush sets are equivalent to a single winding of the same axis connected to a suitably located brush set. This statement might lead to the conclusion that *equal performance* could be obtained by a machine with one field winding and one set of brushes and a machine of *equal dimensions* but possessing two field windings and two sets of brushes. However, a number of electrical, as well as mechanical reasons, exist, which make this impossible and invariably result in a materially poorer performance for the machine with two brush and field sets.

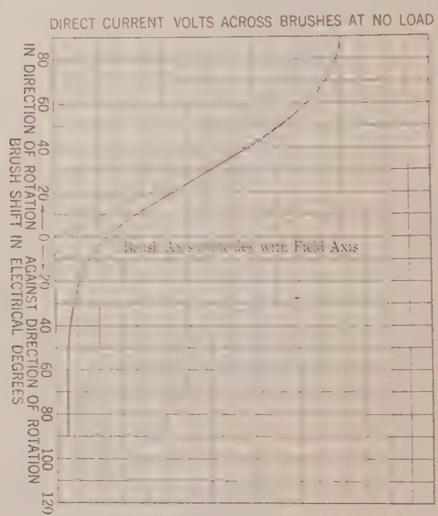

Fig. 2

Mr. Kostko's statement regarding the synchronizing torque may leave the impression that the torque existing during the synchronizing period is in every respect equal to the torque of the machine at synchronous operation. This, however, is not the case under all conditions, but is true just at the theoretical dividing point between synchronism and slip. At speeds below synchronism, the voltage induced in the secondary windings due to the speed between resultant motor field and secondary winding produces an additional induction-motor torque, as shown in my paper already mentioned.

There is another very interesting feature which might be mentioned in this connection: If the load on a self-excited synchronous motor is suddenly increased, the motor can momentarily develop more than its so-called maximum synchronous torque, because a sudden load causes the resultant magnetic field of the motor to fall back suddenly and the velocity of the falling-back magnetic field produces, by induction, an e. m. f. on the field winding which strengthens the excitation until the field has assumed its final position in space. If the machine has an auxiliary secondary winding for starting purposes, then, under the conditions described, a current is induced in this winding also during the falling-back period of the resultant field which adds further to the motor torque until such time when the field has taken its final position in space.

In conclusion, may I state that Mr. Kostko's paper offers a tremendous amount of interesting information and my remarks advocating the attack of the problems of these motors on the simplified basis by neglecting ohmic resistance and leakage reactance, are, in no manner, intended to criticize or minimize the excellent work done by him, but are intended to point out that for the purpose of practical application, the simplified method of dealing with the subject will probably find a wider field of usefulness for the same reasons which made the Heyland circle so much more popular than the Osanna circle, but from the truly theoretical viewpoint, the complete diagram will always remain the most important and the most interesting one.

V. Karapetoff: It would be of interest to go over Mr. Kostko's deduction of the circular locus, using the vector analysis method.[3] With this method, the whole statement of the problem is first written down in the form of vectorial equations, and then some of the variables are eliminated by short-cut methods not possible with elementary algebra or geometry.

Let I be a variable current vector whose locus is a circle of diameter D passing through the origin. The vector connecting the ends of the vectors D and I is $D - I$, a geometric subtraction being understood. According to a familiar property of the circle, the vectors I and $(D - I)$ are perpendicular to each other; hence, in the language of Vector Analysis,

$$(D - I) \,.\, I = O \tag{1}$$

Here the dot between the two factors stands for the so-called *scalar product*. By definition, if A and V are two vectors, their dot product is

$$A \,.\, B = A\, B \operatorname{Cos} (A, B) \tag{2}$$

Since Cos 90 deg. $= O$, the condition that two vectors are perpendicular to each other is

$$A \,.\, B = O \tag{3}$$

Eq. (1) is an application of this relationship to a circle and represents the vector equation of a circle of diameter D passing through the origin.

I shall now show an application of this method to a very simple and well known a-c. locus problem, namely that of a constant reactance x and a variable resistance r in series across a source of constant sinusoidal voltage E. It is required to find the locus of the current I. We have

$$E = I\, r + x\, (j\, I) \tag{4}$$

where $j\,I$ is a vector numerically equal to I and leading it in phase by 90 deg. Since r is variable, and we want a locus, it is necessary to eliminate $I\,r$ from eq. (4). The general method

3. See V. Karapetoff, The Use of the Scalar Product of Vectors in Locus Diagrams of Electrical Machinery; A. I. E. E. Journal, 1923, Vol. 42, p. 1181. A good elementary book on Vector Analysis is by J. G. Coffin (Wileys).

used in vector analysis is to take a scalar product of both sides of eq. (4) with some vector perpendicular to the vector to be eliminated. The vector $I\,r$ is in phase with I; hence both sides must be multiplied by $(j\,I)$, because $(r\,I)\,.\,(j\,I) = O$. The result is

$$[E - x\,(j\,I)]\,.\,(j\,I) = O \quad (5)$$

or, after division by x,

$$[(E\;x) - (j\,I)]\,.\,(j\,I) = O \quad (6)$$

It will be seen that eq. (6) is of the form (1) so that the locus of $(j\,I)$ is a circle of diameter E/x. If desired, eq. (6) can be also written in terms of I instead of $j\,I$. It is only necessary to multiply the both factors on the left-hand side by $-j$, thus turning them by 90 deg. The result is

$$[(-j\,E/x) - I]\,.\,I = O \quad (7)$$

It is true that this particular problem can be just as readily solved by elementary geometry, but I purposely selected the simplest possible case to illustrate the general method.

V. A. Fynn: Mr. Kostko's paper is devoted to a very interesting attempt to develop a general theory of the "exciting" system of self-excited synchronous motors so as to secure a basis of comparison for the several already known types and for such others as further development work may disclose. The paper, however, also deals with the subject of synchronization and touches lightly on the starting conditions.

I have been actively interested in this field ever since 1905 and took out my first patent relating to synchronous induction motors in 1906 (See B. P. 11,298 of 1906). In the last few years I have gone over this ground with a fine-tooth comb in an attempt to discover a polyphase motor with controllable power factor which would be generally acceptable. During the process I too have analyzed this type of machine along very general lines. My experiences in this connection have led me to the conclusion that an exhaustive study of the "exciting" system is not sufficient, that the synchronizing torque is of at least equal importance in the case of self-excited, and of even greater importance in the case of separately excited, synchronous induction motors, and that the asynchronous performance of such machines is almost as vital if a proper basis for the comparison of various types is desired.

It has long been the practise to speak of the unidirectional ampere-turns on the secondary of a synchronous motor as "exciting" ampere-turns, Mr. Kostko does so in his paper, I have often done so myself, but the fact is that said ampere-turns do not always contain *real exciting* ampere-turns and do always carry something else. The term "excitation" conveys to one's mind a picture of the usually few ampere-turns necessary to produce the resultant motor magnetization and with this picture in mind one is very apt to form an entirely wrong conception of the dimensions and practical significance of the commutator of a synchronous induction motor and of the difficulties met with by the designer of such machines. The fact is that the unidirectional ampere-turns on the secondary of a synchronous motor are *always at least equal to the load ampere-turns*, sometimes to *load plus exciting* and mostly to *load plus over-exciting ampere-turns.* At a certain value of lagging power factor, the secondary o a synchronous motor carries exactly that number of ampere-turns as is carried by the secondary of a non-synchronous induction motor under like conditions. At such time all the exciting ampere-turns are carried by the primary, as is the case in non-synchronous induction motors. When a synchronous motor operates at unity power factor then its secondary carries the vectorial sum of load and exciting ampere-turns. For leading power factors its secondary carries load plus over-exciting ampere-turns. The result is that the commutator of a self-excited synchronous or synchronous induction motor carries working plus exciting or plus over-exciting current. Such a commutator must necessarily be large and if anything happens to it or to its cooperating circuits, the machine is put out of commission.

We ought not to speak of the secondary ampere-turns of a synchronous motor as "exciting" ampere-turns.

In the fifth paragraph of his paper Mr. Kostko says that synchronization is accomplished by the synchronous torque—strictly speaking, by a torque which later becomes the synchronous torque. This is true of all the earlier forms of synchronous or synchronous induction motors but is not necessarily true of all synchronous motors. Some of the several motors of this type which I have invented depart from this rule as I have shown in a paper read February 27th last before the Columbus Section of the A. I. E. E. and elsewhere.

In the same paragraph Mr. Kostko states that in separately excited synchronous motors the synchronizing torque is alternating. This used to be so but I have devised separately excited motors with strictly unidirectional and pulsating torques and others with even strictly constant synchronizing torques with quite a variety of synchronizing-torque configurations in between these limits to choose from, see "Engineering" February 20, 1925 and a paper presented to the Schenectady Section of the A. I. E. E. on March 27, 1925.

Just for the sake of historical accuracy it should be stated that contrary to Mr. Kostko's impression as voiced in his paragraph 6, the first self-compounding synchronous induction motor is apparently that of Burge, see B. P. 3227 of 1913, which has two secondary windings and *two* displaced sets of brushes.

I should like to stress my absolute agreement with Mr. Kostko's plea, paragraph 7, that a thorough theoretical investigation go hand-in-hand with experimental work and that haphazard experimenting be avoided. I have preached this doctrine for many years, also when connected with a company for which Mr. Kostko was working at the time, and I have sucessfully practised what I preached. In many cases, including all the synchronous induction motors I have invented, I was able to go even further and to work out the theory quite completely before making a single test, with the result that experimental development work was reduced to practically nothing.

I am bound to disagree with Mr. Kostko as to the opening phrase of his ninth paragraph. This statement of his explains why he has given such scant attention to the asynchronous features of the motors he has discussed as affected by the several arrangements of secondary windings and primary brushes he has referred to. My experience is that the effect of the "exciting" and synchronizing system on the asynchronous characteristics of the machine cannot be so lightly set aside.

The arrangement of secondary windings and primary brushes is now usually used to start, to synchronize and to operate the motor. If they are not so used additional windings are necessary which increase the cost and complicate the manipulations, if they are so used, then the secondary windings act as induction-motor secondaries at starting and their action is modified by the voltage appearing at the commutator brushes included in their circuits. In many cases this results in a considerable unbalancing of the several secondary circuits and a correspondingly poorer starting performance. To illustrate my point, refer to Mr. Kostko's Fig. 12. At the moment of starting, the brush voltage impressed on the secondary 2 leads the voltage generated in 2 by the synchronously revolving motor flux by 90 deg., whereas the brush voltage impressed on No. 1 lags by that amount behind the voltage generated in No. 1.

But of far more consequence is the influence of the configuration of the synchronizing torque on the asynchronous performance of the machine upon a torque demand which exceeds the maximum synchronous torque. As a specific example take a synchronous induction motor provided with the type of "excitation" shown in Fig. 10 and which was disclosed by me in 1916, see U. S. P. 1,337,648. Because of the fact that the unidirectional ampere-turns on the secondary of a synchronous

motor are not "exciting" but really "load plus exciting" ampere-turns, also because these must be accommodated in a single-phase as against a polyphase winding as used in non-synchronous motors and finally because in addition to the winding carrying the unidirectional ampere-turns it is necessary to have another closed winding on the secondary to permit of the motor operating asynchronously, it is found that even by using more copper on the secondary than in the corresponding asynchronous motor the maximum synchronous torque can hardly be made to equal more than two-thirds of the maximum asynchronous torque. If the motor is to have the overload capacity which the material used permits of being developed asynchronously, then part of its overload must be taken care of asynchronously. In the case of a motor such as outlined in Fig. 10, the asynchronous overload capacity is not practically available because the alternating synchronizing torque with unequal positive and negative maxima which can be exhibited by such polyphase motors at sub-synchronous speeds causes their speed to oscillate rapidly under asynchronous overload conditions. It is clear that only the roughest kind of work will permit of such an irregular motive power and such motors are accordingly so rated that their full-load torque equals about half their maximum synchronous and about one-third of their maximum asynchronous torque. This condition is another reason why such motors are very costly.

In prior publications I have shown how this very undesirable condition can be remedied, thus greatly increasing the weight efficiency and therefore reducing the cost of such machines and need not again go into this question here, but the condition just discussed does show the vital importance of the configuration of the synchronizing torque on the weight efficiency of synchronous induction motors and clearly suggests that it does not suffice simply to study their compounding characteristic if a true picture of the relative merits of different types is desired.

I should further like to point out that Mr. Kostko's assertion in paragraph 14, column two, second page, is true enough in so far as synchronizing and synchronous operation is concerned, but not true in regard to starting for the reason that if two displaced windings are used instead of one only and both are connected to the same brush set, the two component windings form a polyphase secondary and make it unnecessary to add a winding on this member which will be active at sub-synchronous and inactive at synchronous speed.

That Mr. Kostko's assertion in paragraph 15 is true, so far as it goes, was demonstrated in my paper "Another New Self-Excited Synchronous Induction Motor."[4] It clearly appears from that paper that Mr. Kostko's proposition is not true when it comes to synchronization. Furthermore, for certain angular displacements there is a great practical difference between the two types. The single-brush-set type is so touchy for certain angular displacements as to be useless in practise, whereas quite steady corresponding operation can be had with the two-set type.

In the last paragraph of Part two, Mr. Kostko states that the pulsations of current and torque during the synchronizing period are unavoidable whether the axis of "excitation" is fixed or variable. This is true for the type with fixed but not true for that with variable position of the axis of "excitation." I have shown how such pulsations can be avoided in separately, as well as in self-excited, synchronous motors.

The motor dealt with under "example 1" is my 1906 motor; not only is the synchronizing torque in this machine "very nearly alternating" but it is actually so and its frequency is double the slip frequency as pointed out in detail in my paper "A New Self-Excited Synchronous Induction Motor."[5]

As to the motor discussed under "example 2," I gave the complete circle diagram for this machine in my contribution to the discussion of the papers presented at the 1925 Midwinter Convention and have shown that at light loads the primary current of this motor lags by nearly 90 deg. behind the terminal voltage, that at a certain load this lag diminishes abruptly and is converted into a lead, after which the lead diminishes steadily with a further increase in load and finally again becomes a lag. It is therefore putting it very mildly to say that the power factor at light loads is not as good as can be expected in synchronous motors.

My investigation of this whole subject has revealed quite a number of interesting conditions not apparent from the Kostko analysis. Thus when using a phase-displaced system of secondary windings connected to a phase-displaced system of brushes on the primary, or more broadly, connected to a plurality of voltages which are phase-displaced when alternating, it is possible to cause the motor to operate synchronously over a wide range of loads and asynchronously at loads below, as well as at loads above, said range. It is further possible to cause the axis of the synchronous unidirectional magnetization on the secondary to travel in the one or the other direction when the axis of the resultant magnetization of the motor moves in a given direction as the load of the motor increases or decreases. This leads to some very interesting combinations to which I may refer in greater detail at some later date. One way to secure the change in question is to reverse the connections between one of the secondary windings and its brushes in Fig. 13.

On the whole, I must admit that my study of the synchronous induction motor has been somewhat disappointing. I feel reasonably certain that I have reached rock bottom, having devised and carefully analyzed some seven or eight different types and worked out a fairly complete general theory which agrees with the results of tests, but I have not found any self-excited synchronous induction motor which I can recommend as a general-purpose motor. My view is that many synchronous motors on any one system of distribution are undesirable; because of their rigid speed characteristic these machines require *instantaneous* response from the generating set and sudden changes in load become so many hammer blows on the system. The fact that self-excited motors require slip-rings as well as a commutator and that both of these are in constant use are undeniably practical disadvantages, particularly in view of the fact that the commutator carries load as well as exciting currents. My conclusion is that synchronous induction machines are much better suited for use as synchronous condensers than as motors. They are much superior to synchronous condensers with defined polar projections now in general use for the reason that no line disturbance can put them out of commission which, so often happens with the pronounced-pole type. Synchronous induction machines used as condensers automatically resume synchronism under any and all conditions and when so used, can be located in sheltered positions where the slip-rings and the commutator will have a chance of operating satisfactorily.

I believe that conditions are much more favorable in the case of larger, separately excited synchronous induction machines and such can no doubt be advantageously used as motors in a number of cases. But when it comes to a general-purpose motor I think that the solution will be found in a compensated non-synchronous machine.

J. K. Kostko: The inversion is undoubtedly the most powerful method of graphical study of circuits yet devised; it originated in this country (F. Bedell and A. C. Crehore, "Resonance in Transformer Circuits," *Physical Review*, Vol. II, 1894-1895, p. 451), but it is much better known and more used abroad. In a circuit containing no independent e. m. f., the current is proportional to the applied voltage; if, for a certain phase angle between the current and the voltage, the value of the former is I' for the voltage E' and I for the voltage E, then the lengths of the vectors $O\,E'$ and $O\,I$ representing E' and I are given by the relation $O\,E' \times O\,I = E\,I'$. If I' and E remain constant, $O\,E'$ describes the locus 1 of the voltage at constant

4. A. I. E. E. Journal, February 1925, p. 164.

5. A. I. E. E. Transactions, 1924.

current, while $O\,I$ describes the locus, 2, of the current at constant voltage; the foregoing relation immediately suggests the possibility of passing from one locus to the other by inversion (for details see *Electrical World*, Vol. 75, p. 724, 1920). It is usually much easier to construct the locus 1 than the locus 2, because, if we start from a known current, we can draw a vector diagram with correct linear and angular relations between the vectors. In practise it is seldom necessary to go through the process of inversion; the construction usually can be simplified by making use of the fact that the angle between two curves remains unchanged by the inversion. Thus, in Fig. 3 the line $A'\,X'$ is the constant current locus of a circuit consisting of the primary resistance r and a variable inductance. Its inverse is the circle 3, of diameter $\frac{E}{r}$. $A'\,X'$ and this circle are the loci of points at which the power from the line is consumed entirely in the resistance r. Therefore, at points common to the circle 3, and to the locus of the motor no power is transferred from the primary to the secondary. The circle, 3, is zero-power or zero-torque circle. It is usually possible to determine the angle between the line $A'\,X'$ and the constant current locus 1; it is also the angle between the final locus 2 and the circle 3. Since the latter is fully determined by the primary resistance, r, this angular relation is an important element determining the locus 2. For instance, in the polyphase induction motors the locus 2 is normal to the circle 3. In a single-phase induction motor it is very nearly normal to it (the exact angle can be calculated from design or test data). In a polyphase synchronous reaction motor circles 2 and 3 are also normal. In a synchronous motor of the type of Fig. 10 of the paper the angle between 2 and 3 is equal to the angle of brush displacement. If two points A and B are inverse of A' and B' respectively, and the constant of inversion with respect to the origin O is c, then $A\,B = A'B' \quad \frac{c}{O\,A' \times O\,B'}$. This relation can be used in order to represent an element such as an e. m. f. by means of a segment in the diagram. The e. m. fs. E, E_1 and E_2 of the paper are represented in this way; other examples can be found in various publications of the writer.

Thus, by the use of various geometrical properties of inverse figures we obtain a complete graphical representation of the performance with its elements shown directly in the diagram. It is hardly necessary to insist on the advantages of such a representation, especially in the study of a new motor type, where calculations should be undertaken only after a clear idea as to the useful range of the design constants has been obtained from the study of the diagram.

A diagram in which the zero-torque circle 3 is used is the exact one, taking into account the primary resistance. The transition to the simplified diagram is easy. If r decreases, the diameter of 3 increases; for $r = O$ the circle 3 coincides with the axis of abscissas. The feeling against the exact diagram is probably due to the fact that the old methods of taking the primary resistance into account are extremely complicated in comparison with the inversion method making use of the circle 3. An article in 1921, TRANSACTIONS [6] shows how the problem of constructing the exact locus of a polyphase induction motor from test data is simplified by the use of this method.

Mr. Weichsel's remark as to the meaning of the equivalence is to the point, but a careful reader is not likely to make a mistake in this respect because the writer took good care to point out in the paper (fifth page, first column) that the torque in the diagram comprises the friction and the loss in the exciting circuits; the net torque is, therefore, somewhat affected by the choice of the exciting system, but not in any definite way. By suitable choice of mechanical features, such as the weight of copper, any one of the two equivalent motors can be made either better or worse than the other; even in the same motor a change of the field copper (leaving the size of conductor unchanged) will affect the net torque without in any way affecting the current locus. The physical change from one exciting system to an equivalent one is affected by the structural features of the motor. No general rules can be given, but each case must be studied individually.

It would be of interest to "go over" my deduction of the current locus using Prof. Karapetoff's method; but the current locus alone is of little value to an engineer. If a comparison of the methods is intended, it would be of greater interest to take up the problem of the graphical study of the motor from the beginning and try to find a solution as general and complete as that obtained in the paper; in my opinion this is the only sensible and fair way of comparing the two methods. The solution of Prof. Karapetoff's example by the inversion method is as follows: let $O\,I'$ be the vector of the current I'; the constant current locus is a line parallel to $O\,I'$ and at a distance $x\,I'$ from it; the current locus at constant voltage E is the inverse of this line, *i. e.*, a circle passing through the origin O, tangent to $O\,I'$ and of diameter $\frac{E\,I'}{x\,I'} = \frac{E}{x}$.

In his discussion Mr. Fynn continuously refers to the features of his separately excited motor as contradicting my conclusions which are derived for the self-excited motor. My statements as to the latter type are not directly attacked, but expressions such as "true as far as it goes," "true enough" etc., are likely to cause some doubt in the minds of the readers. It is well to point out that there is nothing ambiguous or vague in these statements if applied to the motor type for which they have been developed. For that matter, they apply to Mr. Fynn's motor as well, but, for the present, I shall confine myself to the type studied in my paper, because the experience with this type shows that, with such complicated subjects, convincing arguments and a common ground for a profitable discussion can be found only in a rigorous and impersonal methematical study; and, while I have done myself some work on this subject, it would clearly be out of the question to take it up now.

Mr. Fynn's remark that the study of the exciting system is not sufficient, is correct; it is for this reason that I developed in the paper not the theory of the exciting system, as he says, but the complete theory of the self-excited motor. The synchronous (and synchronizing) performance is determined by the constants a, b, α, β, r, x, X; the first four determine the exciting system and are investigated in detail; the last four determine the main a-c. winding. They are used in all vector diagrams for the construction of the current locus, but no further study of these elements is undertaken because they occur in many well known motor types and are quite familiar to the readers.

Mr. Fynn's remark as to the large size of the commutator gives an impression that it is due to the amount of ampere-turns on the secondary. Such is not the case: it should be charged mainly against the self-starting feature of the motor, which involves a very low exciting voltage, as explained in the paper. Mechanically, the commutator must fit the size of the motor, but its output is only a few per cent of that of the motor. If we could use 150-250 volts for excitation, instead of 15-25, the commutator would be as small as structurally possible, regardless of the number of ampere-turns. The danger of sparking and circulating currents in a coil of many turns short-circuited in a strong field also militates against the choice of a high exciting voltage.

In my opinion Mr. Fynn attaches an exaggerated importance to the asynchronous features of the motor as compared to the synchronous performance. His remark as to the voltage appearing at the brushes at starting is true, but he overlooks the order of magnitude of the phenomenon. At starting we may

6. A. I. E. E. TRANSACTIONS, 1921.

have some 500 induced volts in a field winding, and some 20 volts across the brushes, of the same frequency and added vectorially. An unbalance which may be caused by these 20 volts in the two phases of the secondary is really a small matter, the more so because the winding of a self-excited motor is usually made stronger than that of the induction motor in the same frame, so that there is a margin for a slight reduction of the asynchronous torque. If this unimportant action of the brushes be disregarded (or simply avoided by disconnecting the brushes at starting) then the windings of the secondary should be designed (1) as a part of the exciting system, and (2) as a secondary of an induction motor. Plan (1) is extensively studied in the paper; but, as Mr. Fynn puts it, only a scant attention is given to plan (2), because it was not intended to take up here matters pertaining to the induction-motor design, important as it is.

That synchronization is accomplished by the synchronous torque is admitted by Mr. Fynn, at least for the motors studied in the paper; therefore, all parts of the paper dealing with the synchronous performance, *i. e.*, practically the entire paper, can be considered as dealing with the synchronizing torque. It is rather strange to read Mr. Fynn's admonition that "it does not suffice simply to study their compounding characteristics...." etc.

With reference to Mr. Fynn's remark about a motor with two displaced windings connected to the same brush set: I never said that the equivalence of the synchronous and synchronizing operation also means the equivalence of the starting features.

All the motors shown and described in Mr. Fynn's paper "Another New Self-Excited Synchronous Induction Motor" are fixed-axis motors, equivalent to the type of Fig. 10 of my paper, with respect to synchronizing as well as the synchronous operation. If the constants of a motor are changed, for instance by reconnecting field windings, as described in Mr. Fynn's paper, we have not one, but several distinct motors, and to each of them the principle of equivalence to the motor of Fig. 10 applies in full.

In the example 1, Fig. 6, the locus 2, Fig. 7, is normal to the circle of zero-torque 3, of radius $\dfrac{E}{2\,r}$; the torque at a point of the locus is measured by the distance of this point from the chord $D\,C$ (not shown). Due to the curvature of the circle 3 the positive maximum of the torque is somewhat less than the negative; hence the expression "nearly" alternating. Only if r is neglected, the circle 3 coincides with the axis of abscissas and the torque becomes truly alternating.

The variation of the lag of the current in example 2 can be followed in Fig. 9. In practise the motor would not be as bad as it appears, because, on account of losses, the no-load point will be nearer to the origin than D-C-K, and the transition to the lead will occur at a very light load.

The interesting conditions mentioned by Mr. Fynn can be found in the paper; the one which is really important is given quite a prominent place in the chapter on synchronizing. I refer to the motor which has minimum as well as a maximum torque at synchronism. The analytical conditions are given on the bottom of the fifth page. The current locus of such a motor has no common points with the zero-torque circle 3. If the constants are such that its radius is small or vanishes, as in examples 3 and 5, the pulsations of the torque and of the current are also small or vanish. The travel of various fluxes can readily be followed on the constant-current locus 1.

Developments in Electrical Machine Design

By Committee on Electrical Machinery[1]

THE past year has shown a marked advancement in the art of electrical machinery, not only in the successful starting and operation of machines larger than any ever built up to this time, but also in the purchase and partial completion of machines still greater in size. Accompanying the trend towards larger sizes of units, there has been much investigation along the lines of ventilation, insulation, mechanical strength of materials, losses in iron and copper, the effect of expansion and contraction on the insulation of long armature coils, balance of the moving parts and the dissipation of heat from flat surfaces.

New applications of electrical machinery have been made in various industrial lines and transportation. The design of an electric locomotive having d-c. motors and operating from a-c. feeders was adopted. Diesel electric drives have been applied to locomotives in sizes heretofore not attempted for this type of drive.

Turbo-Alternators

During the past year a number of 50,000-kw., 62,500 kv-a. turbo-alternators were successfully put into operation. These machines operate at 1200 rev. per min. and represent the largest single shaft generators yet put into operation. The large size and weight of the various parts of these machines represent a difficult handling and transportation problem. The largest 3600-rev. per min. generator yet to be built was successfully placed in operation during the year, it being rated at 12,500 kv-a., 80 per cent power factor. Machines having 60,000-kw., 60,000-kv-a. ratings, and operating at 1500 rev. per min. are under construction. Quotations are being requested on 75,000-kv-a., 1800-rev. per min. machines, and 83,333-kv-a. cross-compound machines are being considered.

The increasing demand for turbo-alternators of larger and larger sizes has necessitated much development on the part of the manufacturers. This development has been along the lines of improvements in

1. Annual Report of Committee on Electrical Machinery.

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L. L. Elden,	J. M. Oliver,	

Presented at the A. I. E. E. Annual Convention, Saratoga Springs, N. Y., June 23, 1925.

construction and improvements in materials for given purposes, such as retaining bands of greater strength to hold the field end turns in place, iron for stator cores having better magnetic properties, decrease in strand loss by use of twisted conductors and different arrangements of coils, and improvements in the mechanical strength of materials which make up the rotor to allow higher peripheral velocities.

The 62,500-kv-a., 0.8 power factor, 1200-rev. per min., self-ventilated units installed have rotors weighing approximately 200,000 lb., stators, 200,000 lb. and the copper in the machine, 41,250 lb. The stators are wound with approximately 40 miles of insulated wire. The successful operation of the rotors of these large machines has been largely due to many inventions made during the past few years in machines and machine tools.

Tests made recently show that the temperature of the bare copper in commercial machines insulated for 12,000 to 14,000 volts is approximately 15 deg. greater than the temperature determined by a detector placed between the top and bottom coils when the latter is from 55 to 60 deg. above the temperature of the ingoing air; also that the temperatures shown by resistance detectors and thermocouples are about the same, and that the temperatures at the half-way location in the slot are approximately two degrees lower than at the quarter-way.[2]

The problem of self-ventilation is becoming more complex with increasing size of machines, which causes one manufacturer to recommend the desirability of external blowers being used for ventilating future machines. In the past, operating engineers have objected to the use of external blowers on the ground that they are added auxiliaries and therefore an added source of difficulties which may lead to shut-downs. This manufacturer states that the use of closed-circuit ventilation with air coolers, now coming into use, offers added advantages in the use of external blowers and makes their consideration justifiable at this time. The chief advantage of using external blowers in connection with recirculating ventilation systems is that the blower can be placed before the air coolers and therefore the temperature rise in the air passing through the blower, due to rotational loss, can be absorbed by the air coolers and air supplied to the generator at a temperature some five or six degrees lower than possible with self-ventilating systems.

In most cases ventilation is obtained by a multiple radial system in which the air passes radially in and out through the stator core. During the past year there were published results of experiments on this type of ventilation showing that the air is distributed in accordance with a simple hyperbolic or trigometric sine law. Knowledge of the balance state of flow when several branches of air meet and divide in a tube, the intake and discharge, occurring normally to the walls of the tube, depends on the solution of a system of simultaneous transcendental equations. The total pressure required for a certain volume of air per unit time can be expressed by hyperbolic and trigometric cotangents of a certain argument which contains the geometrical dimensions of the air circuit.[3] Large models of turbo-alternators employing different types of ventilation were also set up and tested.

The use of closed ventilating systems has two distinct advantages, in that accumulation of dust on the windings is practically eliminated and fire can be easily extinguished by introducing an inert gas into the system. Several fire extinguishing systems have been installed during the past year. These consist of an arrangement for injecting carbon dioxide gas into the ventilating duct. The arrangement can be either manually operated or operated by the differential and balance relays used for protecting the machine against short-circuited turns or grounds. The results of exhaustive investigation along this line, published during the past year, show that the insertion of 25 per cent carbon dioxid gas, by volume, into the ventilating system will extinguish all flames.

Some of the inert gases have characteristics much better than air for use as the cooling mediums in high speed electrical machines with recirculating cooling systems. Many gases have been considered but the result of much study shows that hydrogen has the better properties if explosion dangers can be eliminated. The advantages which hydrogen offers for this use as compared with air are enumerated below:

Provided air can be excluded, hydrogen is a good fire extinguishing medium. The windage losses are greatly reduced due to the much lower specific gravity of hydrogen and its high thermal capacity. The temperature drop required to transmit heat through various parts of the machine is reduced. The temperature drop required to transmit heat from the hot surfaces of machine to the hydrogen and from the hydrogen to the coolers is less causing the hydrogen to return to the machine at a lower temperature.

Results of tests on generators filled with hydrogen show that it is possible to carry 30 per cent greater load on a machine with the same temperature rise when hydrogen is used as the cooling medium in place of air.

It would be comparatively simple to make a rotating machine hydrogen-tight if suitable shaft packing could be developed. Apparently shaft packing is at the present time, the largest obstacle hindering development of commercial hydrogen-filled machines. Nevertheless, this subject is worthy of further consideration and study.

Recent experiments show that there is considerable loss in the inactive magnetic parts and active magnetic parts of these machines. Miniature turbine-type generators were built for carrying out these investiga-

2. JOURNAL of the A. I. E. E., October 1924, page 926.

3. A. I. E. E. JOURNAL, March 1924, "The Multiple-Radial System of Cooling Large Turbo-Generators."

tions and the percentage losses were found to bear a similar relation to those of larger machines. Wood was substituted for various inactive parts and the magnitude of losses in these parts determined. Experiment showed that there is a high-frequency harmonic flux which causes considerable loss in the end structure and that these losses bear a relation to the magnetic loading of the field. These data together with the results of further study which is now being carried on, give rise to the hope that the efficiency of future machines will be still higher because the nature of losses in heads of machines will be definitely known.

Higher efficiency and lower temperature rises have been secured by grooving the surface of the rotor.

Synchronous Motors

A magnetic clutch has been applied to the synchronous motor allowing the motor to run at synchronous speed before the load is applied. By this means the motor can start heavy loads with a starting torque as high as the pull-out torque of the motor, and synchronous motors can therefore be used where good power factor characteristics are desired but where heavy starting duty is required.

The motor consists of a standard synchronous machine, having a rotor which is not keyed to the shaft, but free to move on a bearing carried by the spider. The field member of the clutch is bolted to the spider while its armature is fixed to the drive shaft. During the starting period, the rotor is brought up to synchronous speed and the drive shaft remains stationary. After the motor field is excited and line voltage applied to the stator winding, the magnetic clutch is excited, drawing its two halves together and bringing the load up to speed.

This motor has the advantage of being adaptable to full automatic, manual, or semi-automatic control. It is of sturdy construction, with desirable power factor characteristics, high load-starting torque and low starting current.

Another motor has been developed which accomplishes the above purposes in a different way. This motor is essentially a synchronous motor but differs mechanically from the ordinary type by having the stator mounted on auxiliary bearings. When the motor is started the rotor remains stationary and the stator comes up to synchronous speed. A friction brake is provided for bringing the stator to a standstill, thus causing the rotor to come up to synchronous speed.

By this method the relative speed between rotor and stator is the synchronous speed of the machine during the starting and running periods. In this motor, as in the one mentioned above, the starting torque available is the pull-out torque of the synchronous motor.

The other advantages are the same as enumerated for the motor above.

Induction motors have been arranged for operating at various speeds by being provided with armature windings which can be connected for various numbers of poles, but until recently the synchronous motor has been inherently a single-speed machine when the frequency of power supply is constant. During the past year a synchronous motor has been developed, and a 5000-h. p. motor actually built, which has pole changing switches for both the stator and rotor windings.[4] This machine has pure synchronous motor characteristics for both speeds and requires no more attention than the ordinary synchronous motor. As the first cost of this motor is only slightly above that of the ordinary synchronous motor for the low speed, it is a practical machine which should broaden the field for synchronous-motor application.

The field poles are constructed so that they can be combined in groups of two having the same polarity, which gives the effect of one half the original number of poles and will therefore cause the machine to rotate at twice the speed when the stator winding is reconnected for the corresponding number of poles. The poles are shaped to compromise between the best shapes for each speed.

Frequency Converters

The year just past has seen not only the largest synchronous frequency changer yet built put into operation, but has also seen an induction-type frequency changer of the same capacity installed and successfully operated. The rating of these machines is 35,000 kw. A second induction frequency changer is now being built which will be rated at 40,000 kw. unity power factor for transfer of energy from the 60-cycle to the 25-cycle systems on which it is used and at 38,000 kw. unity power factor for transferring power from the 25-cycle to the 60-cycle system. This machine will be equipped with a phase-shifting device which will operate hydraulically.

The 35,000-kw. synchronous frequency changer rotates at 300 rev. per min. and has shown an efficiency of 96.1 per cent under operating conditions. This over-all efficiency represents an efficiency of each unit better than 98 per cent which is very high for rotating machinery. The machine is self-ventilated and has very good starting characteristics for a machine of its size. The induction frequency changer was put into operation with no difficulty and when used in connection with tap-changing switches in the air-blast transformer and reactors, showed a larger condenser capacity for power factor correction at reduced loads than could be obtained from a synchronous frequency converter of the same rating.

A new type of frequency converter was developed for tying together two systems, the frequency of each being susceptible to changes. This type is known as the Scherbius—controlled, load-regulating type of set. One machine is a synchronous generator and the other an induction motor having a Scherbius speed-regulating

4. Journal of the A. I. E. E., April 1925, page 339.

set. With this arrangement any desired amount of load can be delivered in either direction up to the limits for which the set is designed irrespective of the relative frequencies of the two systems. Two of these sets having ratings of 6000 kw. were installed during the past year. They form a tie between a 60-cycle and a 25-cycle system and are designed to operate with a total variation in frequency of nine per cent. If the 60-cycle frequency system is constant, the machine rotates at 720 rev. per min., the induction machine operating at above or below synchronism depending upon the frequency of the 25-cycle system.

Transformers

The size of transformers installed and put under construction during the year represents a new high mark. Transformers were installed rated at 15,000 kv-a., 60 cycles, 7200-132,000 volts, three-phase, self-cooled, having a 12,470-volt tertiary winding. The efficiency of these transformers is better than 99 per cent and they have a regulation of 1.1 per cent. Since the largest self-cooled transformers constructed up to the year 1920 were of the order of the 10,000-kv-a., the above units represent a new level for three-phase transformers of this type.

Some 22,000-kv-a. single-phase, oil-immersed, water-cooled transformers, having 12,000-volt delta-connected primaries, and 39,500-volt secondaries, Y-connected to give 68,500 volts, were put into operation. These transformers do not have output ratings as large as other transformers now in service at 60 cycles, but, due to the fact that they operated on 25 cycles, the quantity of materials used in them was much greater than in any transformers of this type yet put into operation. Three-phase transformers, rated at 75,000 kv-a., have been built in Europe.

Improvements made in transformer design include a new type of ration adjuster switch by which the ratio can be altered while the transformer is carrying load. Potheads were developed for mounting on the side of transformers in order to provide a means for bringing underground cable into the transformer without exposing terminals or live parts. The pothead consists of two compartments, one in which the cable terminates and another in which disconnect links are provided. The lower compartment is filled with petrolatum and the other compartment with transformer oil. The conductors from the three-conductor cable are connected to lugs in the pothead which are arranged on the arc of a circle to make the reversing of conductors possible without splicing. A ground switch is now being designed to be located in the upper compartment and controlled remotely from the opposite side of the transformer. This switch will provide a convenient means for grounding the feeder connected to the transformer.

A new device has been developed for indicating the load on pole-type distribution transformers. This consists of two temperature detecting elements, one immersed in the oil and the other mounted in a case for detecting ambient temperatures. These two temperature detectors are connected in series to a pointer which moves by the action of the temperature detector in the oil, which movement is modified by the action of the detector affected by the ambient temperature. When the temperature exceeds a safe value a target shows.

Several installations have been made of a transformer which is filled with nitrogen above the surface of the oil. The nitrogen used is automatically obtained from the atmosphere by passing the air breathed by the transformer through deoxidizing chemicals. The nitrogen, when formed, is conserved by a breathing regulator. The presence of nitrogen over the transformer-oil surface prevents the formation of sludges, (due to oil coming in contact with oxygen in the air), extinguishes fire, eliminates secondary explosions caused by mixture of the gases with air, and cushions primary explosive pressure from the sudden expansion of gases.

A radiator valve has been developed for use between the radiators and tank of large, self-cooling transformers, when it is necessary to remove the radiators for shipment. The valve consists of a tube projected into the radiator flange on the transformer tank and has a gasketed disk which is held against the end of the tube by means of a spring. It is operated by a handle. Rotating the handle 180 deg. in the proper direction opens or closes the valve. When the valve is open the handle may be removed to prevent unauthorized persons from operating it.

A new type of dehydrating breather for transformers has been developed, consisting of a screen basket suspended on a spring of large diameter. When the basket is filled with the proper amount of calcium chloride the spring is compressed and a pointer indicates the correct charge. As the calcium chloride absorbs moisture, the weight is increased and the spring is compressed until the pointer is opposite a refill designation. The calcium chloride is isolated from the humid atmosphere when the transformer is not breathing by means of check valves, and the device is designed so that the calcium chloride will not become saturated until after the refill designation has been reached by the pointer.

Synchronous Condensers

During the year, construction has been started on a 40,000-kv-a., 600-rev. per min. synchronous condenser representative of the largest machine of its type yet to be developed.

Spring Suspension for A-C. Generators

A new method has been developed for preventing the vibration of large a-c. generators from being transmitted from the stator to the supporting foundation. This arrangement consists of a spring mounted in the frame of the machine supporting the entire stator. The development of this device will aid in the successful operation of electric machinery in districts where

vibration is objectionable, especially in the case of single-phase machines which have inherent vibration.

Water Wheel Generators

The installation of the 65,000-kv-a., 12,000-volt, water-wheel generators, at Niagara Falls, has been carried on, and the first unit installed has already operated successfully for more than a year. These machines still represent the largest water-wheel generators built up to the present time. Among other large water-wheel generators about to be installed are a number of 32,500-kv-a., 12,000-volt machines, 23,160-kv-a., 13,200-volt machines, 18,750-kv-a., 6600-volt machines, and 19,500-kv-a., 6600-volt machines. The size of automatically-controlled, water-wheel generators has been advanced to 7300 kv-a.

Synchronous Converters

A number of synchronous converters have been developed for use in congested metropolitan districts. These are completely enclosed on the d-c. end and partially enclosed on the a-c. end. For cases in which systems of the same or different frequencies are tied together through the d-c. side of synchronous converters, a converter has been developed to incorporate special features for successfully withstanding current reversals feeding into a short circuit in either system.

Industrial Motors

New lines of single-phase, adjustable-speed, brush-shifting motors, having a speed range of two to one for constant-torque load have been developed. Single-phase, repulsion induction motors, having squirrel-cage rotor construction, without centrifugal devices, have been extended to include a reversing type capable of reversal from full speed in one direction to full speed in the opposite direction. Another new development in industrial motors is a new line of synchronous motors for driving ammonia and air compressors. These have double-bar, squirrel-cage windings, giving better control of current and torque under starting conditions and permitting the motors to be thrown on, full voltage. Induction motors of higher speeds with high-reactance secondary windings for full-voltage starting, totally enclosed motors with a special ventilation for operation in inflammable atmospheres and a new type of bearing which prevents air from getting into the bearing housing and oil from getting out, have been developed. Motors with enclosed collector rings have been put on the market for use in oil wells and similar service.

A New Self-Excited Synchronous Induction Motor[5]

The pure induction motor has characteristics which differ considerably from the pure synchronous motor. Each motor has advantages and disadvantages, the advantages of one being lacking in the other. A number of motors combining in part the advantages of both types of machines have been developed in the past and during the last year, there has been further development along this same line.

A paper was recently published describing a new type of motor which has induction motor characteristics during the starting period and synchronous motor characteristics during the running period, the source of excitation when running as a synchronous motor being supplied from within the machine. The rotor of this motor carries a polyphase winding supplied with power through slip-rings and a commuted winding. The stator has an exciting winding displaced ninety electrical degrees from the axis of the brushes, and a neutralizing winding coaxial with the brush axis. Both these windings are connected to the brushes through separate variable resistances. A third variable resistance is inserted across the brushes to relieve the commuted winding under severe starting conditions.

When the polyphase winding is connected to the supply lines, a revolving flux is set up which revolves at synchronous speed when the rotor is at a standstill and is stationary in space when the rotor is revolving at synchronous speed. Since the revolving field cuts the two stator windings, displaced by ninety electrical degrees when the rotor is revolving at a speed less than synchronism, currents are set up in these windings which give a torque similar to that generated in an induction motor. These currents close over the brushes and the commuted windings and are regulated by the adjustable resistances which act in a way similar to the adjustable resistance inserted in the secondary of a slip-ring induction motor. As the rotor approaches synchronous speed additional torques are developed by the stator windings which pull the motor into step, at which time the magnetic field revolving with respect to the rotor becomes stationary in space and the brush voltage becomes unidirectional, thereby causing the magnetizations produced by the stator windings to be unidirectional.

Whenever the torque demand is greater than the maximum synchronous torque of the motor, the machine will drop out of step and become an induction motor in effect, giving the same asynchronous overload capacity as may be obtained from a corresponding slip-ring, induction motor. As soon as the torque demand is sufficiently reduced the machine will again fall into step. The motor is compounded to give power factor regulation by proper location of the brush axis with respect to the unidirectional magnetization of the secondary. All windings of the machine are utilized at all stages of starting and running.

A New Type of Single-Phase Motor[6]

Sometime ago a single-phase motor was developed which had series characteristics during the starting period and shunt characteristics during the running period, but as the motor contained a centrifugal device for decreasing the reactance of one of the windings,

5. Journal of the A. I. E. E., August 1924.

6. Journal of the A. I. E. E., July 1924.

the motor was never adopted for production. However, this motor was a stepping-stone to a new type of motor having the same series and shunt characteristics and having no centrifugal device. The latter is termed the squirrel-cage repulsion motor and had been brought out during the past year.

This new motor consists of essentially a repulsion motor with a squirrel-cage winding inserted in slots which are located beneath the slots bearing the commuted winding. Since the induction motor winding is imbedded deeply in the rotor core, it has high reactance during the starting period, due to the relative high frequency of the induced current. However, when the speed of the rotor approaches synchronism, the frequency of the rotor currents is relatively low and the action of the squirrel-cage winding comes into play.

Since the reactance of the commuted winding is inherently low, the current flows mainly in this winding during the starting period, and torques are produced similar to those of a plain repulsion motor during the starting period. At full load the squirrel-cage and commutated windings deliver approximately equal amounts of energy.

Commutation is greatly aided by the action of the squirrel-cage winding due to the fact that it absorbs the energy which would otherwise cause sparking on account of induced electromotive force in the short circuited coil. To aid commutation further by absorbing the energy from the leakage flux which does not interlink with the squirrel-cage, a thin sheet of metal is inserted radially between the squirrel-cage winding and the commutated winding. This metal can be made of high resistance on account of the high frequency commutation and therefore does not materially interfere with the distribution of flux during the starting.

The motor has a very much better power factor, both at synchronism and below synchronism, than the plain repulsion motor. The commutation is practically perfect due to the action of the squirrel-cage winding in connection with the metal strips mentioned above. The efficiency is also considerably raised by the addition of the extra winding.

A New Alternating-Current General-Purpose Motor[7]

Another type of a-c. motor has been put on the market, which combines the starting characteristics of an induction motor with the good power factor characteristics of the synchronous motor, in a self-contained unit which needs no auxiliary machines for excitation. This motor will operate at unity or leading power factor and will carry very heavy temporary overload.

The motor consists of a rotor having a polyphase a-c. winding and a commutated winding, and a stator having a field winding and an auxiliary winding. The auxiliary winding is physically located at 90 deg. from the field winding and is closed upon itself. The field winding is connected to the commutator brushes. The power supply lines are connected to the polyphase winding on the rotor through slip rings.

The commutated winding does not appreciably affect the torque of the machine at standstill or low speed, but at higher speeds the commutator voltage enters into giving better synchronizing characteristics. When the machine is operating at synchronous speed a d-c. potential is present across the brushes, which serves as a direct-current source of supply for exciting the field. The machine, therefore, acts as an induction motor during the starting period and as a synchronous motor exciting itself during the running period. When the load reaches 150 to 200 per cent of full load, the machine drops out of step and continues to run as an induction motor. As soon as the load is again decreased to within these limits, the machine falls back into step and operates as a synchronous motor. The losses in this motor are comparable to those of an equivalent induction motor. However, the new motor has a tendency to be slightly less efficient at fractional loads and slightly more efficient at overload. The size of this motor is approximately the same as for the corresponding slip-ring induction motor.

Obviously there is a very large field for motors having the marked advantages enumerated above, not only for new installations where they can be made to operate at unity power factor, but also in older installations where a large number of induction motors have already been installed, in which case the lagging reactive kv-a. can be compensated by operating the new motor at leading power factor. However, the cost of these motors is considerably more than the corresponding induction motor, as may be expected.

A "Wool-Yarn" Oiling System for Small Motors

Many classes of service for small motors call for long operation of the motor without attention. Such service demands an oiling system for the motor bearings which is capable of supplying the bearings with the proper amount of oil for long periods without cleaning or the addition of oil.

A line of small motors has been put on the market which have a lubrication system called the "Wool-Yarn" System, consisting of a number of continuous strands of wool yarn placed over the shaft and projecting down into the oil in the well. In this system the oil is carried from the well to the shaft by capillary attraction instead of a revolving ring as is the usual practise. The compartment carrying the yarn and oil is practically dust proof, every precaution having been taken to prevent dust from entering around the shaft.

Even though this system is not applicable to motors larger than a few horsepower, it has marked advantages for small motors, in that the yarn acts as a filter for the oil and the oil in the well is not agitated which helps to confine it to the well. The oil capacity is increased by

7. Journal of the A. I. E. E., April 1925.

the amount held in the yarn and the motor will operate for long periods without re-oiling.

Surface Iron Losses with Reference to Laminated Materials[8]

Additional experimental work on surface iron losses with reference to laminated materials was carried on during the past year. The experiments were made on special test machines, the roters of which contained no windings other than exploring coils. The machines were rotated by direct connected d-c. motors, which were calibrated in order that the losses in the test machines could be obtained from their inputs. The surface losses were obtained by separating the fundamental frequency losses from the total losses.

It was shown that the hysteresis and eddy-current components of the surface loss can be approximately separated graphically. Skin effect decreases the losses as the decrease in eddy current loss is considerably greater than the increase in hysteresis loss. In the case of salient poles the enamel on individual laminations decreases the surface losses only slightly, which would not justify the extra manufacturing expense in most cases, even though it may materially affect the relative hysteresis and eddy losses. It was stated that the hardening of lamination edges, due to punching, affects the hysteresis surface loss appreciably if the punchings are not annealed.

Repeated Thermal Expansions and Contractions Their Effect on Long Armature Coil Insulations[9]

During the past decade the length of armatures has been increased about five feet due to the increase in the capacity of machines. Since the coefficient of thermal expansion of the copper conductor in armature coils is about fifty per cent larger than that of the mica and paper insulation, there is a considerable difference in linear expansion of the two in armature coils. Recently much experimenting was done to determine the effect of this unequal expansion on long armature coils.

Experimental coils were placed in slots formed by stacking iron laminations in the same manner as they are placed in the slots of an alternator armature. Imitation vent ducts were situated at intervals in the iron so that the entire construction was comparable to a four-slot section of a large machine. The coils consisted of square brass tubes and were 118 in. in length. The insulation was standard for 13,200 volts. Thermocouples were placed at proper points for indicating temperature. The brass tubes were heated by passing current through them from a suitable transformer, and were cooled by passing them through air for certain experiments and water for other experiments where a greater change in temperature was desired.

Automatic equipment was used for heating and cooling the coils which consisted of time delay relays for putting on the current, starting the blower, etc. 7800 cycles of temperature changes of approximately 75 deg. cent. were given the coils, followed by 2512 cycles of 100 deg. cent. difference in temperature, 825 cycles of 130 deg. difference in temperature, and 400 cycles of 160 deg. temperature difference. The hottest temperature reached by the coils ranged betwen 150 and 180 for all tests.

After the coils were put through the above cycles, which were comparable to many years of service in a commercial machine, they were removed from the slots and inspected. The paper was somewhat darkened in color and was robbed of most of its mechanical strength. However, it was strong enough to retain its form about the conductor and to withstand the removal of the coils from the slot. The discoloration was greater at the imitation vent ducts than where the insulation was in contact with the stamping due to the fact that air could reach the paper more easily at those points. During the tests the coils were given a high potential test of 23,000 and 37,000 volts at intervals, and withstood these voltages without breakdown.

Tooth Pulsation in Rotating Machines[10]

Results of experiments have been published on the tooth pulsation in rotating machines, where both members are slotted. A method for checking the magnitude of flux pulsation was presented consisting of using metallic electrodes similar in shape to the machine teeth in connection with an electrolyte of mercury to represent air. Current is caused to flow through the teeth by applying voltage between the two members, with a magnitude proportional to the magnitude of flux that would flow under analogous magnetic conditions. The results obtained in this way are, in general, slightly lower than those shown by two methods of calculation; but the agreement is fairly good.

If the ratio of the mercury to electro resistance is small, corresponding to the effect of saturation in the iron, the effect of saturation may be experimentally determined. It was shown that for actual machines the effect of saturation on pulsation amplitude cannot be calculated by adding directly the air gap and tooth reluctances, on account of the permeability of the iron not being constant.

Gaseous Ionization in Built-Up Insulation[11]

Experiments on the gaseous ionization in built-up insulation were conducted showing that the losses due to internal ionization caused a progressive deterioration of insulation, even though the absolute values of these losses in well constructed armature bars are small compared with dielectric losses of other types. The use of mica was shown to reduce the conductivity of the insulation and minimize the action of internal ionization. Even though the micafolium content can be somewhat reduced without seriously affecting the insulating prop-

8. Journal of the A. I. E. E., August 1924.

9. Journal of the A. I. E. E., November 1924.

10. Journal of the A. I. E. E., July 1924.

11. Journal of the A. I. E. E., January 1924.

erties over long periods, the use of high mica content appeared desirable due to variations in manufacturing process.

Effects of Time and Frequency on Insulation Tests of Transformers[12]

The use of the induced potential method for testing the insulation of transformers has increased during the past few years. In order to keep the exciting current within a reasonable range during these tests, it is necessary to use frequencies higher than normal. Since the frequency used affects the dielectric strength of most insulating materials, the fair length of time during which high voltage is applied in the case of higher frequencies than normal is somewhat less than that for normal frequencies.

During the past year the results of experiments made to determine the fair length of time for higher frequencies were published. It was shown that the rupture voltage of oil is the same for both sixty and 420 cycles. Due to the fact that the behavior of oil alone is very erratic no well defined relation can be made between time and dielectric strength. However, for the first few seconds, time decreases the strength quite rapidly, after which the effect decreases and is probably entirely absent after two or three minutes. The momentary strength ranges from 25 to 30 per cent higher than the one-minute strength.

The strength of solid insulation decreases with an increase in frequency. The effect of time on the strength of oil and solid insulation in series is approximately the same as for solid insulation alone until the oil distance exceeds the solid insulation thickness, after which it begins to be the same as for oil without barriers.

When solid insulation is under considerable stress the breakdown by creepage is not affected by time nearly so much as is the puncture voltage of solid insulation. Frequency does not materially affect the creepage failure of solid insulation which is under no stress. However, if the insulation is under considerable stress the voltage for failure decreases with increased frequency in about the same order as the puncture voltage of solid insulation. The effect of frequency on the puncture voltage of solid insulation and oil in series is approximately the same as for solid insulation, where the thickness of the solid insulation is greater than that of the oil. When the oil distance exceeds the thickness of the solid insulation the effect approaches that for oil without barriers.

Obtaining Steady High-Voltage Direct Current from Thermionic Rectifier without a Filter[13]

The ordinary polyphase high-voltage rectifier gives a practical constant direct-current potential, which has a ripple superimposed on each side of the mean of approximately five to seven per cent of the total d-c. voltage. This ripple may be ironed out to a considerable degree by the use of a filter consisting of condensers and reactors which are somewhat expensive, especially for high voltages.

During the past year work was done on the development of a special type of a-c. generator having the proper low voltage wave form for giving a more nearly smooth rectified direct potential and provisions were made for manually or automatically varying the wave form to maintain a steady potential for varying load demands.

The Application of the Saturated Core Reactor and Regulator[14]

The use of direct-current saturation in the iron cores of static a-c. apparatus in radio work has been in vogue for sometime, and of late is being used commercially in voltage regulators and current-limiting reactors. However, due to cost and inefficiency, the saturated-core voltage regulator and current-limiting reactor are at present confined to specific uses in which speed of operation is desired in the case of the voltage regulator and increasing reactance with alternating current is desired in the case of the current-limiting reactor.

During the past year, saturated iron-core current-limiting reactors were installed in a large central station between the essential auxiliary bus fed by a house generator and a miscellaneous auxiliary bus fed by a house transformer. These reactors are designed to carry 660 kv-a. under normal operating conditions, at a reactance drop of fifteen per cent. The short-circuit reactance is approximately 38.5 per cent, which will not allow more than 1710 kv-a. to pass through the reactors at normal voltage. Should the house generator be carrying full load and supplying 660 kv-a. to the miscellaneous auxiliary bus through the reactors, a disturbance on that bus could not overload the house generator more than 42 per cent due to the action of the reactor.

The Transverter

A machine has been developed in England for converting polyphase alternating current into direct current and vice versa. Polyphase a-c. voltages of values low enough to be generated in large commercial alternators can be transverted into continuous potentials on the order of 100,000 volts.

The a-c. supply lines are connected to a series of transformer banks which transform the original voltage to the desired value and, in addition, convert the fundamental number of phases into a large number of phases, 36 for example. The 36 phases are then connected in the proper order to a commutator which remains fixed in space, the brushes being the rotating member. The brushes are mounted on a shaft and rotated inside the commutator instead of being placed on the outside as is the usual practise. If only two brushes were used and there were only as many commutator segments as phases, the brushes would have to be revolved at the

12. Journal of the A. I. E. E., February 1924.

13. Journal of the A. I. E. E., November 1924.

14. Journal of the A. I. E. E., July 1924.

synchronous speed of a corresponding two-pole motor. However by using more brushes and segments, properly arranged, the speed can be made to correspond to that of a four- or six-pole motor.

The transverter recently built and displayed in England used ten commutators in series to give 20 d-c. amperes at 100,000 volts, and was designed to be supplied with 50-cycle, three-phase current at 6600 volts. The speed of the brushes is 1000 rev. per min.

This device can be used for a number of purposes, such as obtaining high-voltage direct current from low-voltage alternating currrent, low-voltage direct current from high-voltage alternating current, low-voltage direct current from high-voltage direct current (by adding another set of windings and commutators), and a given alternating frequency from another frequency. All these processes are reversible.

The Subcommittee wishes to express to Mr. J. A. Brooks its appreciation of the valuable assistance which he has rendered to it in the preparation of this Report.

Committee Organization

The organization of the Committee on Electrical Machinery comprises a number of Subcommittees including the following;

1. The review and preparation of technical papers in the field of electrical machinery, H. M. Hobart, Chairman.
2. The preparation of a résumé of the year's progress in the electrical machinery art for the presentation at the Annual Convention, J. C. Parker, Chairman.
3. Preparation of short memoranda of timely interest relating to electrical machinery, for publication from month to month in the Journal, E. H. Hubert, Chairman.
4. Subcommittee on Electrical Machinery Research, V. Karapetoff, Chairman.
5. Subcommittee on Electrical Machinery Standards, C. A. Adams, Chairman.

Provisions are made for further subcommittees which can be described as Regional Subcommittees. Each member of the Committee on Electrical Machinery is invited to examine the practicability of establishing in his vicinity a Regional Subcommittee to deal with subjects in which he is especially interested. The member includes in the Subcommittee a group of fellow-specialists and he is free to go outside of the Committee on Electrical Machinery for this purpose.

As an example of one of these Regional Subcommittee's may be mentioned that organized by Prof. B. F. Bailey. It deals with induction motors and generators and research subjects relating thereto. As Professor Bailey is located at the University of Michigan he has associated with himself in this Subcommittee Prof. James F. Fairman, Mr. Norman S. Yost and Mr. L. N. Holland, all of whom are located at or near Ann Arbor.

The studies and discussion leading to the above organization of the Committee on Electrical Machinery took considerable time and the Subcommittees have not made as much progress this year as had been hoped. However, the Electrical Machinery Research Subcommittee has held meetings in which several matters have been profitably discussed.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

SHORT CUT DESIGN FOR ELECTRICAL ADVERTISING

Advertising quite naturally groups itself into two separate and distinct methods of presenting its message to the public. Circulating advertising, the first of these, may be leisurely, argumentative, and thorough in the lesson it teaches and since it is read in the library or office, it is designed for such leisurely reading.

On the other hand, display advertising is fixed in its position and relies therefore for its effectiveness, upon being conspicuous and unavoidable; it must get its message across in a flash, out of doors, in all kinds of weather, at many different distances and at many different angles. In any case, however, it must convey its message in a very short time for it must do its work on the minds of moving people. For this reason it must be very simple, striking and impressionistic.

Of all forms of display, electrical advertising has the greatest variety of characteristics by which it may be made effective. It has brightness, which in contrast with the night is alone often sufficient to create in a flash a lasting impression in the minds of passers-by, conveying the entire message of the display. It may also have motion, brilliant colors and unlimited size as well as uniqueness, fantastic shape and a limitless variety of forms and positions.

Factors Involved in the Selection of the Proper Sign for a Given Location

In addition to electrically illuminated poster boards and similar advertising material, there are three general types of electric signs. The first of these, (the exposed lamp sign as it is called), is best suited and most frequently used for all electrical advertising which must be effective at greater distances. These signs may be designed to possess strongest attracting power and the greatest individuality; they may be made most brilliant and they excel in adaptability to the use of color and motion.

The enclosed lamp sign, consisting of luminous letters of glass either in small round lenses, painted sheets, or shaped opal plates mounted in a metal case, is best suited and most used for all small location markers in low hanging positions. Signs of this type are effective at all ordinary viewing distances up to 500 ft. This fact, together with their adaptability to neatness of design, has made them an accepted standard for day as well as night advertising, particularly at distances of less than 250 ft.

TABLE I

Factors to be Determined		Type of Sign: Exposed Lamp Signs	Enclosed Lamp Signs	Silhouette Signs
Range of Effectiveness		250 ft.—to Several Miles	0-250 ft.	0-1000 ft.
Letter Height (in feet). This quantity determines the maximum legibility distance.		$H = \frac{\text{Greatest Viewing Distance (in feet)}}{250}$	$H = \frac{\text{Greatest Viewing Distance (in feet)}}{300}$	$\frac{\text{Greatest Viewing Distance (in feet)}}{350}$
Lamp Spacing (in feet). This factor determines the smoothness of illumination.		$S = \frac{\text{Shortest Viewing Distance (in feet)}}{1,000}$	Lamps spaced not more than six inches apart in any direction.	Lamps spaced on 6 inch centers
Number of Lamps		$N = \frac{H}{S} \times \text{No. of Letters} \times 2\frac{1}{2}$	$*N = \frac{W H \times \text{No. of rectangles}}{40}$	
†Lamp Size	District Brightness	Lamp Wattage‡	Lamp Wattage	Lamp Wattage
	1	75–100	60–75	100
	2	75	60	75
Obviously the brightness of the display is influenced by this factor.	3	50– 75	50–60	75
	4	50	50	60
	5	25– 50	50	60
	6	25	40–50	50
	7	15– 25	40	50
	8	15	40	40
	9	10– 15	24–40	40
	10	10	25	25

*For the enclosed lamp sign the filament centers of no two adjacent lamps should be more than 6 inches apart. For illumination of large surfaces this requires lamps at the corners of equilateral triangles, six inches on a side covering the pattern. For the illumination of a sign, the units (words, letters or pictures) which are made up of rectangles require a number of lamps per rectangle equally spaced to cover it, equal to the nearest even number than N in the equation shown above. W is the width and H the height of the rectangle in inches.

†This applies to clear lamps only. When blue glass lamps are desired, the next larger size will often be found to be desirable.

When colors are used, either from a spray coating on the lamp or a color hood over it, a larger wattage is necessary to give the same brightness effect. The wattages in the table should be multiplied as follows:

For yellow light—multiply wattage by 1.5
For orange light—multiply wattage by 2
For amber light—multiply wattage by 2
For green light —multiply wattage by 3
For red light —multiply wattage by 4.

Lamps larger than 100 watts should not be used, but the correct wattage per foot line-length as thus determined. Where color is employed two lamps will often be required in places where one clear lamp was otherwise sufficient.

‡For distances in excess of one mile, use the equation,

$$\text{Lamp watts} = 10 \frac{\sqrt{\text{distance (in feet)}}}{\text{district brightness factor}}$$

The third and last type is known as the silhouette sign consisting essentially of a brightly lighted background against which the darker letters stand out in bold relief. Such a sign is easy to keep clean and may be made very attractive in appearance although it is not so widely used as the other types.

TABLE II
District Brightness Factors

No.	Description of District
1	Extremely bright Square such as Times Square, New York City.
2	Very bright centers such as State St., Chicago.
3	Bright Squares in large cities; Cadillac Square, Detroit; Playhouse Square, Cleveland.
4	White Ways in Large Cities. Public Squares in smaller cities.
5	Business districts (no White Way) in large cities. White Ways in smaller cities.
6	Business districts in smaller cities. Outlying districts in large cities.
7	Outlying districts in smaller cities. Centers of small towns.
8	Darker outlying districts with an occasional store, etc.
9	Lighted highway but no stores.
10	A small isolated display—no street lights or store windows.

Important Factors in Sign Design

To design effective electrical advertising displays, it is necessary to be a good artist as well as a good engineer. Without the imagination of the artist displays may be flat, uninteresting, monotonous, and unattractive, and naturally, less effective; while without the knowledge of engineer, displays may be too large, too small, too spotty, too bright or too dull.

The engineer must first make a survey of the location. He wants to know the greatest distance at which the display must be effective for the height, and size of the letters will influence maximum distance at which the sign will be legible. He also wants to know the shortest distance at which the display must appear well, for the smoothness of the illumination at a given viewing distance is influenced almost entirely by the lamp spacing—another factor which the engineer must determine. These two distances ,then, limit the range of effectiveness of the display.

The general brightness of the district to be made brighter by the display is another point to be considered by the engineer. The accompanying Table II giving

district brightness factors may be used for this purpose, thereby guaranteeing that the brightness of the sign will be in accordance with that of the surrounding district.

The underlying principles of sign design are rather complex, and the evaluation of its fundamentals has involved rather elaborate engineering study; in fact many books and a life long study might be devoted to the art of electrical advertising display design. However, once these principles are known and understood, they may frequently be reduced to rule-of-thumb methods which, though simple, inherently take care of the more technical considerations. Thus the engineering features of sign design may be compressed with a fair degree of accuracy into a few simple equations and tables. The most important of these were recently presented in a paper before the Illuminating Engineering Society,[1] and are summed up in the first of the accompanying tables.

To use these tables, it is assumed that the artist's conception of the display, as it is to appear before the eyes of the public, has the approval of the prospective sign owner as well as that of the engineer. In this display the central figures, around which all the art work is grouped, are a number of rectilinear letters,—. wording. This arranged the most difficult portion of sign design is complete, for indeed the artistic conception can be accomplished only through an intimate knowledge of the advertising program and aspirations of the company, as well as the genius and initiative of the artist.

The problem then is for the engineer to work out the details of construction. Thus, for him it is merely a matter of following the simple equations and using a little judgment. If the picture is then right, the display cannot fail. But without him it might be disastrous, for it is up to him to construct a sign in such a way that the picture painted by the artist will be deeply impressed upon the minds of the passers-by.

AIRPLANE BEACONS

A mountain top near Dijon, France, about 250 miles from the nearest salt water is equipped with a beacon of a billion candle power which will guide air pilots of the night flying line connecting Paris and Marseilles.

Although this French airplane beacon is the most powerful as yet built the United States has a very comprehensive system of air light houses. There are, among others, electric beacon lights of a half billion candle power at the Chicago, Iowa City, Omaha, North Platte and Cheyenne airplane landing fields. These beacons are to identify these fields but their light is so powerful that when a plane is approaching the earth the beacon is turned off and the field itself is then floodlighted.

Further to mark out the route for night flying extending for a thousand miles west of Chicago there are five million candle power electric beacons every 25 miles which also serve to indicate the location of emergency landing fields. Thus with the light way that extends from New York to Chicago it would be possible for an airplane pilot to start from New York after dark and have a line of light guide him all the way from there to Cheyenne provided his plane could travel fast enough so as not to be overtaken by the rising sun before reaching Cheyenne just to the east of the Rocky Mountains.

The New York to Chicago light airway which is now being put in commission, because of the rough country, has electric beacons 12 to 17 miles apart instead of every 25 miles which is the rule west of Chicago. These air-ways are operated upon a schedule and not all lighted at once. When a plane arrives at one of the regular landing fields the electric beacons behind it are turned off and the signal is sent out to light those ahead of it. Thus when the plane is again in the air the pilot can set his course by the lights ahead. In this manner both lights and planes travel across the country between dusk and dawn.

1. "Short-Cut Design for Electrical Advertising." Presented before the annual convention of the Illuminating Engineering Society by C. A. Atherton, Illuminating Engineer, National Lamp Works of G. E. Co., Cleveland.

SPECIFICATIONS FOR RAILWAY SIGNAL PRIMARY-BATTERIES

As the result of a series of tests conducted by the Bureau of Standards of the Department of Commerce, a preliminary specification for the primary batteries used to operate railway signals has been prepared and submitted to those interested for consideration.

Caustic soda primary batteries are used to a large extent in the operation of railway signals, and the Bureau was requested by the battery committee of the American Railway Association to draw up specifications covering the performance of such batteries. The committee has held three meetings at the bureau during the past year. It was found that sufficient data were not available to permit the drawing up of specifications, so a series of tests was started to obtain the necessary information. Tests on 93 batteries have been completed each one involving a large number of measurements of dimensions and voltages. The tests were made both at room temperature and at 32 deg. fahr. The latter condition is most important because of the low temperature to which these batteries are subjected during the winter months. As the outcome of these tests a preliminary draft of specifications has been prepared through the joint cooperation of the battery committee of the American Railway Association, representatives of the manufacturers, and the Bureau of Standards.

Increased safety in travel will be one of the important indirect benefits from the work.

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month.

The Pacific Coast Convention

TENTATIVE PROGRAM OF PAPERS AND EVENTS

A splendid program has been arranged for the Pacific Coast Convention, which will be held in Seattle, Washington, September 15th to 19th. The technical papers will cover distribution, transmission, hydroelectric developments, education, research and marine application. A number of trips of engineering and scenic interest has been scheduled with special plans for the ladies who attend. There will be golf, and the tournament for the John B. Fisken cup will be a particular feature.

As may be seen from the tentative arrangement published herewith the subjects of distribution systems and practises will occupy a large portion of the program. The revision or the extension of distribution systems is a problem which is becoming very important in the West, and eight papers from engineers in eight different parts of the country will discuss distribution practises in their respective locations. There will also be three papers on the coordination of distribution with communication systems.

Transmission will be another important subject and papers on stability, design of long spans and other phases will be presented.

Another group of papers will cover engineering education and research.

An unusual event will be a meeting scheduled for the representatives of Sections and Branches. At this meeting, matters relating to activities of Sections and Branches, particularly those of the West, will be discussed.

Convention headquarters will be at the Olympic Hotel, Seattle, and all meetings will be held there. Those who plan to attend the Convention should make reservations by communicating directly with the hotel.

The convention arrangements have been made by a well organized local committee, working actively for the past several months. This committee consists of the following members: G. E. Quinan, Chairman, C. N. Beebe, Hiram W. Clark, Harry P. Cramer, E. J. DesCamp, W. C. DuVall, F. R. George, John Harisberger, C. A. Heinze, Joseph Hellenthal, Charles A. Lund. C. E. Magnusson, James S. McNair, C. E. Mong, L. W. W, Morrow and C. R. Wallis.

TENTATIVE PROGRAM OF PACIFIC COAST CONVENTION

SEATTLE, SEPTEMBER 15-19, 1925

(NOTE: Several of the papers listed here had not yet been officially approved and some had not been received when this issue of the JOURNAL went to press.)

TUESDAY MORNING SEPTEMBER 15TH

Address of Welcome—Dr. Henry Suzzalo, President of the University of Washington.

HOTEL OLYMPIA—CONVENTION HEADQUARTERS

President's Address—Dr. M. I. Pupin, President of the American Institute of Electrical Engineers.

Reports of Committees, etc.

TUESDAY AFTERNOON, SEPTEMBER 15TH

Symposium on Hydroelectric Power Development in Pacific Northwest

The Baker River Power Development, W. D. Shannon, Stone & Webster, Inc.

The Lake Cushman Dam, B. E. Torpen, City of Tacoma.

The Oak Grove Development, H. A. Rands, Portland Electric Power Company.

Water-Power Development of the Alouette-Stave-Ruskin Group of the British Columbia Electric Railway Company, Ltd., E. E. Carpenter, British Columbia Electric Railway Company, Ltd.

Steam-Power in Its Relation to the Development of Water-Power, R. C. Powell, Pacific Gas & Electric Company.

TUESDAY EVENING, SEPTEMBER 15TH

President's Reception, Italian Room, Olympia Hotel. Dancing.

WEDNESDAY MORNING, SEPTEMBER 16TH

Engineering Education and Research

Some New Features and Improvements on the High-Voltage Wattmeter, J. S. Carroll, Stanford University.

A Stationary Type of Laboratory Standard Wattmeter, H. V. Carpenter, Washington State College.

On the Nature of Corona Loss, J. J. Hesselmeyer and J. K. Kostko, Stanford University.

The Study of Ions and Electrons for Electrical Engineers, Harris J. Ryan, Stanford University.

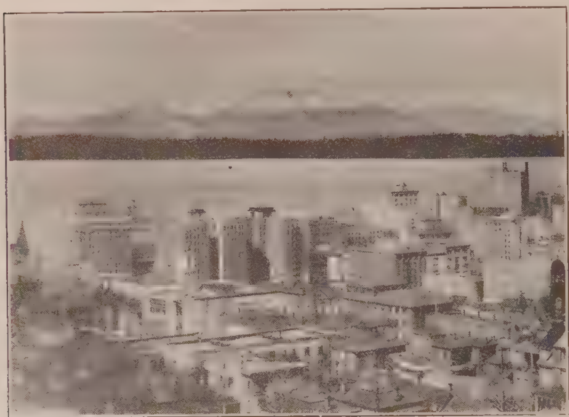
Engineering Research—A Vital Factor in Engineering Education, C. E. Magnusson, University of Washington.

Relation Between Engineering Education and Engineering Research, R. W. Sorensen, California Institute of Technology.

WEDNESDAY AFTERNOON, SEPTEMBER 16TH 1:00 P. M.

Several of the beautiful golf courses in the vicinity of Seattle will be available to members and their friends.

Tournament play at the Inglewood Golf and Country Club for the John B. Fisken Cup. This tournament will be open to any member of a Pacific Coast Section.



A PORTION OF SEATTLE'S BUSINESS DISTRICT, HARBOR AND OLYMPIC MOUNTAINS

2:30 P. M.

Entertainment for the Ladies, Bridge, Tea, Seattle Yacht Club, Montlake Park.

During the afternoon the *K-B* Boat will be on exhibition.

WEDNESDAY EVENING, SEPTEMBER 15TH

Application of Electric Propulsion to Double-Ended Ferry Boats, Alexander Kennedy and F. V. Smith, General Electric Company.

Lecture: *The K-B Propeller*, F. K. Kirsten, University of Washington.

THURSDAY MORNING, SEPTEMBER 17TH

Transmission-Line Design and Operation

Stored Mechanical Energy in Transmission Systems, J. P. Jollyman, Pacific Gas & Electric Company.

Spans Having Supports at Unequal Elevations, G. S. Smith, University of Washington.

The Long Span Across the Narrows at Tacoma, J. V. Gongwer, and A. F. Darland, City of Tacoma.

220-Kv. Transmission Transients and Flashovers. R. J. C. Wood, Southern California Edison Company.

The Line of Maximum Economy, E. A. Loew and F. K. Kirsten, University of Washington.

12:30 to 2:00 p. m.

Luncheon. Sections and Branches Committee Meeting.

THURSDAY AFTERNOON SEPTEMBER 17TH, 2:00 TO 5:00 P. M.

Transmission-Line Design and Operation (Cont'd.)

Fundamental Considerations Regarding Power Limits of Transmission Systems, R. E. Doherty and H. H. Dewey, General Electric Company.

Analytical Discussion of Some Factors Entering into the Problem of Transmission-Line Stability, C. L. Fortescue, Westinghouse Electric & Manufacturing Company.

Symposium on Distribution Practise

Distribution-Line Practise of the San Joaquin Light & Power Corporation, L. J. Moore and H. S. Minor, San Joaquin Light & Power Corporation.

Improvement in Distribution Methods, S. B. Hood, Northern States Power Company.

THURSDAY AFTERNOON, SEPTEMBER 17TH

Entertainment for the Ladies.

Sight Seeing Trip over Seattle Scenic Boulevards.

THURSDAY EVENING, SEPTEMBER 17TH

Dinner Dance in the Italian Room of the Olympic Hotel.

FRIDAY MORNING, SEPTEMBER 18TH

Symposium on Distribution Practise (Con'td.)

The 60-Cycle Distribution System of the Commonwealth Edison Company, W. G. Kelley, Commonwealth Edison Company.

A High-Voltage Distributing System, Glen Smith, City of Seattle.

A Distribution System to Supply Increasing Load Densities in Residential Areas, M. T. Crawford, Puget Sound Power & Light Company.

Distribution Practises in Southern California, R. E. Cunningham, Southern California Edison Company.

Power Distribution and Telephone Circuits—Inductive and Physical Relations, D. I. Cone, The Pacific Telephone and Telegraph Company, and H. M. Trueblood, American Telephone and Telegraph Company.

FRIDAY AFTERNOON, SEPTEMBER 18TH

Sumposium on Distribution Practise (Cont'd.)

Induction From Street-Lighting Circuits—Effects on Telephone Circuits, R. G. McCurdy, American Telephone and Telegraph Company.

The Radio-Interference Problem and the Power Company, L. J. Corbett, Pacific Gas & Electric Company.

Opportunities and Problems in the Electric Distribution System, D. K. Blake, General Electric Company.

Engineering and Economic Features of Distribution Systems Supplying Increasing Load Densities, L. M. Applegate, General Electric Company, and Walter Brenton, Northwestern Electric Power Company.

FRIDAY, SEPTEMBER 18TH—SATURDAY, SEPTEMBER 19TH

Short trips to Industrial Plants, Central-Station Properties and Scenic Points.

Annual Convention of the Association of Iron & Steel Electrical Engineers

Success seems assured by the program which has been planned for the Annual Convention of the Association of Iron & Steel Engineers, to be held at Philadelphia, September 14th-19th inclusive. The Committee in charge has worked most unceasingly and have been rewarded with the fine promise of the program developed. Oil circuit breakers in connection with high tension Switching will be one of the subjects to come before the convention, and some others will be frog-leg armature windings; Report of the Electric Heating Committee, their subject being "From the Ingot to the Finished Material"; auxiliaries and auxiliary drives for steam electric generating sttaions; extending the heat cycle in boiler operation by the

use of preheated air combustion. The Committee invites questions on any or all of these subjects as well as any information that will tend to give breadth of application and success to the carrying out of the convention program. There will be an informal dance Monday evening and the regular Annual Banquet Thursday evening, the Philadelphia Section having charge of the entertainment schedule.

Comments Requested on Preliminary Draft of Standards

In the work of revision of the A. I. E. E. Standards another section has been brought by the Working Committee to a point where comments from the Institute membership are desired. The new section is No. 9, Induction Motors and Induction Machines in General.

This draft of the Standards has been prepared by a working committee in the appointment of which every effort has been made to select the men from all branches of the art most competent to contribute directly to the development of an accurate and generally acceptable set of Standards. Copies of the above are now available, without charge, and all interested are requested to apply to Institute headquarters. Write direct to H. E. Farrer, Secretary Standards Committee, 33 West 39th St., New York, N. Y. This section of the Standards was offered for comment in the June JOURNAL but because of extensive changes it is again posted.

Chemical Exposition at Grand Central Palace

About twenty leading American colleges and universities have filed applications for their students of chemistry and chemical engineering to take the one week's course of intensive training in practical technique of chemical engineering to be held in conjunction with the tenth Exposition of Chemical Industries, at Grand Central Palace, New York City, during the week of Sept. 28th-Oct. 3d. More than three hundred students are expected to enroll before the closing date. A course of lectures is now being prepared and examinations will be held at the close of the course, as a number of colleges have designated their willingness to give students credit toward their degrees for any work done at the Chemical Exposition. Professor W. T. Read, of the Chemistry Department, Yale University, is in charge.

American Engineering Standards Committee

1925 NATIONAL ELECTRICAL CODE APPROVED BY A. E. S. C.

The 1925 edition of the National Electrical Code, which is shortly to be published by the National Board of Fire Underwriters, will announce on its cover and title pages, its approval as an AMERICAN STANDARD by the American Engineering Standards Committee. The biennial revision of this bible of the electrical wiring industry was performed by the National Fire Protection Association as the sponsor organization, through a Sectional Committee with 39 organizations represented in its membership, including several Federal, State and Municipal bodies in addition to the various technical, industrial and commercial associations concerned.

The Code is said to have wider recognition and use by inspection authorities and others than any other set of technical regulations.

In its compilation and revision it has drawn upon nation-wide sources of experience and practise.

The first printing will be 100,000 copies.

RATING RULES AND DEFINITIONS FOR ELECTRICAL CONTROL APPARATUS

Another step toward the national unification of industrial practises is registered in the announcement by the American Engineering Standards Committee of the approval of the "Electrical Industrial Control Standards" submitted jointly by the American Institute of Electrical Engineers and the Electric Power Club. These are based upon previous standards of the Institute and of the Club, and upon practises that have been developing for many years. The document approved includes:

1. Specifications of service conditions.
2. Definitions of different types of control apparatus, and of parts, and of functions of the apparatus, together with a classification of controllers, switches, and resistors.
3. Rules for the rating of the apparatus in accordance with the duty to be performed.
4. Dielectric tests.

The temperature rise permitted in wire wound coils is 50 deg. cent. for class O materials, 65 deg. for class A, and 85 deg. for class B, when measured by thermometer applied to the hottest accessible part of the apparatus. A 20 deg. greater rise is allowed when the temperature is determined by increase in resistance of windings. The temperature rise of laminated contacts is limited to 50 deg. cent., and of solid contacts to 75 deg., the measurement to be made by thermometer.

The conditions and methods of making the temperature tests, and for determining the dielectric strength, are also laid down in the standard.

STANDARD CONNECTIONS AND TERMINAL MARKINGS

The approval, as American Standard, of a system of connections and markings for electric power apparatus is announced by the American Engineering Standards Committee. The standard is the result of a revision of the work of the Electric Power Club which has been developed over a period of years. The most important part of the revision has consisted in systematizing the work into a general plan not only for present needs, but to provide sufficient flexibility for future development.

Previously confusion has existed, but in the new system sub-numbers are used to differentiate between the various terminals of each class. These letters were chosen wherever possible so as to conform to the practise of many years and to cause as little consternation as possible for those making practical use of the diagrams presented.

The new system is being submitted to the International Electrotechnical Commission for adoption as an international standard.

Additions to the Electrical Engineering Staff of the M. I. T.

Another notable electrical engineer of high theoretical and practical attainments has joined the professorial staff in the Electrical Engineering Department of the Massachusetts Institute of Technology, in the person of Doctor H. B. Dwight.

Doctor Dwight studied at the University of Toronto and McGill University. He graduated from the Electrical Engineering Course of the latter in 1909 and went into the employ of the Canadian Westinghouse Company where for years he has been in charge of the design of direct current and synchronous alternating current rotating machinery. His studies and experience in this employment have made him an authority on the design of rotating machinery over a wide range of characteristics. He has

also given a great deal of interest to the development of power transmission, has planned important proposed projects and is the author of three books relating to power transmission and allied subjects; besides having published numerous scientific articles in the TRANSACTIONS of the American Institute of Electrical Engineers and other journals, relating to the theory of electric circuits, design of electric machinery and the transmission of electric power. A new edition of his book on Transmission Line Formulas has just been issued.

In 1924 McGill University conferred upon him the degree of Doctor of Science.

The Electrical Engineering teaching staff of the Massachusetts Institute of Technology already includes experienced teachers, theoreticians and writers over a wide range of the field such as Jackson, Laws, Lawrence, Lyon, Timbie, Bush, Dellenbaugh, Ricker, Hudson, Tucker, Dahl and numerous other younger men, and the addition of Dr. Dwight to this staff is further evidence that the authorities of the Massachusetts Institute of Technology realize the importance of electrical engineering to the industries and are determined to maintain their Electrical Engineering Department on the highest practicable level.

Accompanying Dr. Dwight's appointment was the promotion of Professor F. S. Dellenbaugh, Jr., to an Associate Professorship, and of Messrs. Bowles, Dahl and Lansil to Assistant Professorships.

New Haven Machine Tool Exhibition

The Annual New Haven Machine Tool Exhibition will be held as usual in the Mason Laboratory of Mechanical Engineering, Yale University in September 8, 9, 10 and 11, 1925. The exhibition is under the auspices of the New Haven Section of the American Society of Mechanical Engineers, the New Haven Chamber of Commerce and the Mechanical Engineering Department of Yale University. It is designed to encourage an appreciation of the production value of machine tools and to exhibit the latest developments in the machine tool industry.

NATIONAL RESEARCH COUNCIL

HIGHWAY RESEARCH BOARD

At a recent meeting of the Executive Committee of the Highway Research Board of the National Research Council it was decided to hold the Fifth Annual Meeting of the Board at Washington, D. C., on December 3 and 4, 1925. Progress reports received from the Chairmen of the Research Committees show that they are conducting important studies on almost every phase of highway development, including finance, design, construction and maintenance, thus assuring a successful annual meeting. The program for the Fifth Annual Meeting is now being prepared and will soon be announced.

ENGINEERING FOUNDATION

ARCH DAM TO BE TESTED TO DESTRUCTION

More than $70,000 has been raised by a special committee of the Engineering Foundation, and, toward the settlement of a scientific problem centuries old, this will be applied to the erection of an arch dam on the Stevenson Creek, a tributary of the San Joaquin River, about sixty miles from Fresno, California. The dam will be 100 ft. high and both American and European engineers are aiding in the plans for its erection. It is to represent in actual structure plans "new to engineering effort" and approximately $100,000 will be spent to determine the validity of this concrete arch design. In the execution of this investigation, the American Society of Civil Engineers will act in cooperation with the United States Bureau of Reclamation, the States of California and Oregon, the City of San Francisco, Los Angeles County, power companies, irrigation districts, universities and individual engineers.

It is purposed to build the test structure first to a height of 60-ft., then after making test, extend the dam, two feet in thickness, 40 ft. farther in 10-ft. lifts until the total elevation of 100 ft. is reached. The up-stream radius of curvature of the arch will be uniform, 100 ft. The placing of concrete masonry is expected to begin in October, and it is planned that when the structure has reached an elevation of 60 ft. it will be subjected to tests and observations of one year's duration. In order that no damage may result from the testing process, the dam will be located in a rough, rocky mountain gorge. An important water supply conduit of the Southern California Edison Company will afford water for the tests without dependence upon local rainfall and melting snow.

Book Review

THE TRANSACTIONS OF THE FIRST WORLD POWER CONFERENCE, London, June 30th to July 12th, 1924. London, Percy Lund. Humphries & Co., Ltd., 4 v., 6423 pp., illus., maps. 10 by 6 in. cloth.

These four handsome volumes contain the papers presented at the first World Power Conference, and the discussions they provoked. A fifth volume, containing an elaborate index, is in preparation.

Few engineering congresses have left so extensive and elaborate a record of their proceedings; few have excited such widespread interest, if the use of this report may be taken as an indication. The Conference brought together delegates of many countries, as well as a large number of engineers from all quarters of the globe; the papers were of high quality, so that the published record is a valuable summary of power resources and their present utilization.

The scope of the Conference was a wide one; the available and utilized power resources of the world were reported upon very fully, the papers upon this subject filling an entire volume. Upon the production of water power, the preparation of fuels and the production of steam power, the contributions were sufficient to fill another volume which is a comprehensive review of the best practise of various lands in the development of water powers, water-wheel design, the distillation of coal, producer gas, peat, shale-oil, and in the utilization of wood waste, as well as of modern steam power plant design and practise.

The subjects contained in Volume III deal with internal combustion engines, gas, such sources of power as wind, alcohol and natural steam, the transmission and distribution of power by electricity, research, standardization and illumination.

Papers on a variety of subjects appear in volume four. The varied uses of power in industry and for domestic purposes, in electrochemistry and electrometalurgy, and for transport on land and sea are discussed and described. Various economic and financial problems are treated, as are the governmental policies of various countries. Several papers on education, health and publicity conclude the work.

A work so broad in scope and so varied in character cannot fail to offer something of interest to every engineer, whether he deals with the production of power or its use. The list of contributors includes many of our best authorities and the articles, with their numerous illustrations and maps, give a graphic picture of the present state of power engineering.

PERSONAL MENTION

MACKENZIE MACINTYRE has been made assembly foreman for the DeForest Radio Company, Jersey City, N. J.

ROBERT C. BARTON has left the service of the Iowa Service Company at Missouri Valley, Ia., and is now superintendent of the Caliente Public Utilities, Caliente, Nevada.

ALBERT B. JUNKINS is now construction engineer for the Electrochemical Company, Baltimore, Md., having resigned from the service of the American Sugar Refining Company, of that city.

WILLIAM MCCLELLAN AND PETER JUNKERSFELD, engineers and constructors of New York, St. Louis and Washington, D. C., have opened a Chicago office, with Stephen Gardner as district manager.

WILLIAM B. FLYNN, formerly electrical engineer with Day & Zimmerman, Philadelphia, has been made construction engineer in charge of all work of the Georgia Railway & Power Company, Atlanta, Ga.

WALTER F. AMAN has resigned from the office of Assistant Physicist of the National Bureau of Standards, Washington, D. C., to accept position as electrical engineer in the office of the Pennsylvania Railroad System, Altoona, Pa.

W. H. WAGNER, who for the past fifteen years has been connected with the Chicago Office of the General Electric Company, on July 1st assumed new duties as superintendent of the Los Angeles Service Shop of the company.

ARCH ROBINSON, who for the past two years has been in charge of construction work for the J. G. White Engineering Corporation at Parco, Wyoming, in the erection of an oil refinery for the Producers and Refiners Corporation, has now returned to New York City.

ELMER O. THOMPSON, who has for the past five years been employed by the American Tel. & Tel. Company in the Development and Research Department, has joined the David Grimes, Inc., manufacturers of radio receiving instruments.

GILBERT L. CHADWICK, who was associated with Hollis French & Allen Hubbard, Consulting Engineers, as assistant electrical engineer, has made new affiliations with Anderson-Coffey Co., Electrical Contractors and Engineers, also of Boston.

J. S. FOGERTY has recently entered the employ of the Brooklyn Edison Company for service in their electrical engineering department. For the past year, Mr. Fogerty has been doing electrical construction work with the Phoenix Utility Co., Guatemala, C. A.

A. H. DRUMMOND has resigned from the position of division inspector in the Distribution and Transmission Dept. of the Westchester Lighting Co., and has accepted position as assistant to the distribution engineers of the Pennsylvania Power and Light Company, Allentown, Pa.

H. B. VINCENT, for the past fourteen years associated with Day & Zimmerman, Inc., Philadelphia, as engineer on construction and operation, has accepted a position as manager of field engineering service with the R. Thomas & Sons Company, and will be located at their Ohio works, East Liverpool, O.

F. LEROY SCHAEFER has severed his connections with the engineering department of the American Rolling Mill Company to accept position as assistant superintendent of construction for the Du Pont Engineering Company, and is now located at Charleston, W. Va., in connection with a new development at Belle, W. Va.

F. R. COMBES, who for the past three years has been chief assistant in the Switchgear Development Department at the works of the General Electric Company, Wilton, Birmingham, has returned to New Zealand and is now electrical engineer for the Auckland Branch of Messrs. A. S. Peterson & Co., agents for the Swedish General Electric.

RALPH D. WICHMAN, electrical and civil engineer with the Pacific Gas and Electric Co., San Francisco, for the past three and a half years, in charge of design of transmission substations, distribution substations, steam generating stations and steam heating plants, is now associated with Wichman & Albers, Engineers Service Bureau, San Francisco.

LOUIS D. FLETCHER, Assistant Examiner, U. S. Patent Office, having graduated from George Washington University with degree of LL.B., took the District of Columbia Bar Examinations, June 1925, and will now hold position with Darby & Darby, New York City, as Patent Attorney, specializing in radio work. He resigned from the Patent Office July 1st, 1925.

EDGAR W. BROCKMEYER, who has been chief engineer of the Master Electric Company, Dayton, Ohio, since its incorporation five years ago, has resigned to join Mr. S. A. Brown, former vice-president and sales manager of the Leland Electric Mfg. Co., in the formation of a new company to be known as the Brown-Brockmeyer Co., Dayton, Ohio. Mr. Brockmeyer will be its vice-president.

W. R. PHIPPS has become division manager for The Wichita Gas Company, Wichita, Kansas. Mr. Phipps is a veteran Public Service official, having been for fifteen years with the Henry L. Doherty organization, owners of this new gas company,

C. GALLAGHER, since leaving England, has been made assistant engineer and designer for Elder Smith & Company, Ltd., Perth, Western Australia.

LEO A. SOLVEY, after several years with the Ebro Irrigation and Power Co., Barcelona, Spain, as superintendent of one of the operating and maintenance departments, and later engaged in consulting engineering and commerical work in several European countries, has returned to New York City and is at present engaged in appraisal work of the N. Y. Edison Co., same being made by Murrie & Co., Engineers.

WILMER P. HOLBEN, who has held a position as assistant distribution engineer with the Pennsylvania Power & Light Company, Allentown, Pa., has resigned to accept the position of senior engineer in Distribution and Transmission section, Engineering Dept. of the Philadelphia Co., Pittsburgh. The principal subsidiaries of this company are the Duquesne Light Co., the Pittsburgh Railway Company and the Equitable Gas Co., all of which operate in the vicinity of Pittsburgh.

DUGALD C. JACKSON, JR., has been placed in charge of the Department of Mechanical and Electrical Engineering at the Speed Scientific School, a new school of the University of Louisville. This school is to be run on a cooperative basis with the industries in and about Louisville, and Professor Jackson will receive the first students this Fall. For the past two years he has been assistant professor in charge of Electrical Engineering at Trinity College, Duke University, Durham, N. C.

CHARLES S. RUFFNER, Vice-President and General Manager of the Adirondack Power & Light Corporation, Schenectady, N. Y., has been elected President of the Mohawk-Hudson Power Corporation, a large holding corporation now seeking authority to acquire the capital stock of the utility corporations serving the Mohawk and upper Hudson valleys. Mr. Ruffner has been connected with the power industry for over twenty years, having been with the Mississippi River Power Distributing Co., the Union Electric Light & Power Co., the North American Co., and subsidiary companies in capacity of vice-president during that period Mr. Ruffner served as a Manager of the Institute from 1916 to 1920 and Vice-President from 1920-21. He has also been a member of many A. I. E. E. committees. He entered the Institute in 1902 and became a Fellow in 1912.

Obituary

Herbert M. Beechinor, who for some time past has been associated with the Electrical Testing Laboratories, New York City, in the capacity of Assistant Engineer in Cable inspection, died at the Mount Vernon hospital July 20th, after a brief illness. Mr. Beechinor was a native of Mount Vernon, N. Y. Born in the year 1884, his schooling was through the Classon Point Military Academy, Notre Dame University and University of Michigan, where he took a three and a half years' course in Electrical Engineering, graduating in 1906. After graduation, he spent five and a half years in the Testing Department of the New York Edison Company, one year with the Duquesne Light Company, Pittsburgh, Pa. and one year with the American Electric Fuse Company, Cleveland, Ohio. He joined the Institute in 1920.

James Roy Portnell, superintendent of the electrical distribution department of the Union Electric Light and Power Company, Duluth, Minn., died July 2d in St. Luke's hospital, that city. Mr. Portnell left St. Louis, where he has recently made his home, June 18th, for Minnesota, where he expected to spend his vacation fishing in Vermillion Lake, but was suddenly stricken and did not survive to return from the hospital to which he was taken for treatment. Born in Iuka, Kansas, January 25, 1886, Mr. Portnell's general and technical education after elementary schooling was through the University of Arkansas, where he took his course in electrical engineering. He has been with the Union Electric Light and Power Company since 1906, and his progress had been steady. Entering as draftsman in 1907, he became distribution engineer and in 1916 was promoted to superintendent in charge of aerial and underground construction, maintenance and operation of the electrical distribution and transmission system of the City of St. Louis. He became a member of the Institute in 1923 and his record with the Union Electric Light and Power Company speaks for itself with regard to his accomplishment in technical development.

Stephen Jay Fuller, an Associate of the Institute since 1920, passed away recently. Mr. Fuller was born at River Falls, Wisconsin, Dec. 6th, 1879. In 1899 he graduated from the Larimore High School, North Dakota, and in 1908 from the University of North Dakota College of Mechanical Engineering. In 1909 he entered Sibley College, Cornell University, for a three years' course, teaching engineering and studying electrical engineering as a post graduate student. While attending the Larimore High School, he started his practical career as an apprentice in the Municipal Electric Light Company, Larimore, and from 1900 to 1909 served as electrician and electrical superintendent in various places in North Dakota and Jennings, Ia. In 1912 he was made assistant to the assistant manager of the Eastern Michigan Power Company, Jackson, Mich., but in 1917 entered the employ of the Michigan Railway Company, Albion, Michigan, as inspector of electric car equipment. In 1918 Mr. Fuller served in the Navy Department as inspector of electrical equipment, testing new and untried apparatus to determine the suitability of same for government service. At the time of his death, he was Insurance Engineer for the Consolidation Coal Company, New York City.

Harold Hayward Clark, chief engineer of the Wico Electric Company of West Springfield, Mass., and for many years chief electrical engineer of the United States Bureau of Mines, Pittsburgh, died at Ellsworth, Me., his native town, July 8th, after a long illness. In his early life, he attended common school and High School at Ellsworth, thence becoming a freshman in Worcester Polytechnic Institute, where he remained through his sophomore year. He then went to the University of Maine, Orono, Maine, for his junior and senior years of college, graduating from the electrical engineering course with a degree of B. M. E. in electricity, in 1899. He also returned for a post graduate course to obtain the E. E. degree. In 1899 he became instructor in mechanical drawing and descriptive geometry at the University of Maine, but left in 1900 to take a practical position in the Testing and Engineering Department of the General Electric Company. He remained with them until 1907, when he entered the United States Navy Department as electrical expert aid. In 1909 he was chosen electrical engineer of the U. S. Geological Survey, and it was during that year that he joined the Institute as an Associate; in 1912 he changed his grade to Member. In 1922, Mr. Clark was with the Witherbee Igniter Company, Springfield, Mass., but returned to the Wico Electric Company in 1923, to become their chief engineer, the capacity in which he was serving at the time of his death.

Past Section and Branch Meetings

SECTION MEETINGS

Cleveland

Address by Farley Osgood, National President, A. I. E. E. Several motion pictures were shown. The following officers were elected: Chairman: C. L. Dows; Secretary-Treasurer, J. F. Schnable. May 21. Attendance 103.

Detroit-Ann Arbor

Radio Communication, by G. H. Clark, Radio Corporation of America. Illustrated with slides and moving pictures. The following officers have been elected: Chairman, G. B. McCabe; Vice-Chairman, F. H. Biddle; Secretary-Treasurer, H. Cole. June 16. Attendance 100.

Erie

Early History of the Electrical Art, by James Burke, Burke Electric Co., and M. J. Fogarty, M. L. Elder, Hermann Lemp and Wm. H. Reynolds, all of General Electric Co. Illustrated with slides. June 9. Attendance 80.

Kansas City

Prime Movers, by F. S. Dewey, Kansas City Power & Light Co. June 11. Attendance 23.

Los Angeles

Inspection trip to the new 30,000-kw. steam plant of the Los Angeles Gas and Electric Corporation at Seal Beach. Dinner was served at the California Institute of Technology, after which Professor R. W. Sorensen conducted a number of interesting experiments in the physics laboratory and the million-volt testing laboratory. June 13. Attendance 161.

Milwaukee

The Essentials of City Planning, by G. S. Rogers, City Planning Engineer of Milwaukee. The speaker traced city planning from the Roman days on, devoting a large part of his talk to automobile traffic. Joint meeting with Milwaukee Engineers' Society. The following officers were elected: Chairman, H. R. Huntley; Secretary, L. F. Seybold. June 17. Attendance 40.

San Francisco

Transmission of Pictures over Telephone Lines, by A. J. Champreux, Pacific Telephone & Telegraph Co. The talk was illustrated by a complete sending and receiving station. April 24. Attendance 240,

Our Present Prosperity and the Engineer, by W. G. Vincent, Jr., Pacific Gas & Electric Co., and

The Value of Graphic Expression as Applied to Engineering, by Henry Bosch, Jr., Pacific Gas & Electric Co. Dinner was served by the Pacific Gas and Electric Company. May 22. Attendance 250.

Spokane

Annual Meeting. The following officers were elected: Chairman, G. S. Cooey; Vice-Chairman, J. Wimmer; Secretary-Treasurer, R. McKay. A dinner preceded the meeting. June 5. Attendance 17.

Toledo

Annual Dinner. The following officers were elected: Chairman, A. H. Stebbins; Vice-Chairman, O. F. Rabbe; Secretary-Treasurer, Max Neuber. June 12. Attendance 20.

BRANCH MEETINGS

Marquette University

Transverse Armature Reaction of Synchronous Motors, by Messrs. McClurg and Kempf. The following officers were elected: Chairman, C. H. Legler; Vice-Chairman, R. M. Franey; Secretary, M. J. Smith; Treasurer, U. Carniero. May 21. Attendance 35.

University of South Dakota

Illustrated lecture. May 29. Attendance 22.

University of Southern California

Business Meeting. May 28. Attendance 30.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES JULY 1-30, 1925

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ALTERNATING CURRENTS AND TRANSIENTS, TREATED BY THE ROTATING VECTOR METHOD.

By F. M. Colebrook. N. Y., McGraw-Hill Book Co., 1925. 195 pp., 9 x 6 in. cloth. $3.00.

Written to provide students of electricity with a knowledge of this useful method for the solution of many problems encountered in the study and practise of electrical engineering. The method is developed as simply as possible in the first part of the book, the remainder being given to illustrations of its application in certain typical branches of electrical theory.

AMERICA'S GREATEST DAM, MUSCLE SHOALS, ALA.

By William Benjamin West. 2nd edition. N. Y., Frank E. Cooper, 1925. 62 pp., illus., 8 x 11 in. cloth. $2.00.

A general, popular review of the Muscle Shoals project, with descriptions of the two nitrate plants situated there, and of the Wilson Dam. Illustrated by many photographs.

BAU GROSSER ELEKTRIZITATSWERKE.

By G. Klingenberg. 2nd edition. Berlin, Julius Springer, 1924. 608 pp., illus., diagrs., plates, 11 x 8 in., boards. 45.-gm.

A revised and improved edition, in one volume, of this important work. Much new material has been incorporated and many parts of the book have been rewritten, while the entire arrangement of the matter has beeen altered to a more logical one.

The work is now arranged in nine chapters. The first sets forth the theoretical principles involved. Chapter two discusses the relation between size and factor of use, and the economy and the cost of power. The supply of electricity to large cities is then considered, followed by a discussion of the distribution of power over large districts. The author then takes up the right lines for the design of large electric plants.

The succeeding three chapters present in detail three typical examples of actual plant construction.

CAR BUILDERS' CYCLOPEDIA OF AMERICAN PRACTICE. 11th edition, 1925. Comp. & edited for the American Railway Association, Division V, Mechanical, by Roy V. Wright and Robert C. Augur. N. Y., Simmons-Boardman Pub. Co., 1925. 1162 pp., illus., diagrs., 12 x 9 in., cloth. $8.00.

The new edition is similar to that issued in 1922, but the work has been brought up to date by including the new designs that have appeared and by carefully revising the older material, so that current practice is fully covered.

CHEMISTRY OF ENGINEERING MATERIALS.

By Robert B. Leighou. 2nd edition. N. Y., McGraw-Hill Book Co., 1925. (International chemical series). 538 pp., illus., 8 x 6 in., cloth. $4.00.

The purpose of this book is to provide a textbook of industrial chemistry suited to the needs of students of structural and mechanical engineering. It presents, in suitable compass. information concerning the chemical properties of the materials used in building and in machinery, from the viewpoint of the user rather than of the maker.

This edition has been thoroughly revised and partly.

CONSTRUCTION OF WELLS AND BORE-HOLES FOR WATER SUPPLY.

By J. E. Dumbleton. Lond., Crosby Lockwood & Son, 1925. 134 pp., illus., 9 x 5 in., cloth. 10s 6d.

An English work intended to condense in a general practical manner many subjects connected with well work. Discusses the theory of springs, the yield of wells, construction of wells, well drilling, pumps, the properties and methods of analysis of water. Intended to replace Swindell and Burnell's "Rudimentary Treatise on Wells and Well-Sinking."

COURS D'AVIATION.

By A. Desaleux. Paris, Gauthier-Villars & Cie., 1925. 246 pp., diagrs., 10 x 7 in., paper. 35 fr.

A textbook for beginners, based on experience as an instructor and as a flyer. Covers the elements of aeronautics, including aerodynamics and its application to air-planes, the construction of air-planes, instruments, operation of motors, use of maps and the principles of meteorology.

ENTWERFEN IM KRANBAU.

By Rudolpf Krell. with a supplement, "Elektrische Kranausrustungen," by Christian Ritz. Mun. u. Ber., R. Oldenbourg, 1925. 2 v.: v. 1, Text; v. 2, Plates. 13 x 9 in., cloth. 32.-mk.

This work is not intended so much for use as a textbook on crane design, as to be a handbook for designers. The book discusses the various elements of cranes—keys, bolts, rivets, chains, ropes, drums, tackle, bearings, axles, brakes, gearing, etc.—giving the necessary formulas and numerical data, with diagrams from which the proper dimensions for ordinary cases may be obtained at once. The atlas contains over one thousand sketches of crane details and many useful graphs. In the appendix are a number of examples, fully solved, which show the use of these tables.

FRANZ REULEAUX, UND SEINE KINEMATIK.

By Carl Weihe. Berlin, Julius Springer, 1925. 100 pp., ports., 8 x 5 in., boards. 3.-gm.

An appreciative sketch of the man and his work, by a former pupil. The main events in Reuleaux's career as an investigator and teacher are considered, and a chapter given to a consideration of the philosophy and influence of his conception of kinematics. Reuleaux's important paper, "Kultur und Technik" is republished and there is a bibliography of his writings

FRICTION CLUTCHES.

By R. Waring-Brown. Lond. & N. Y., Isaac Pitman & Sons, 1924. 124 pp., illus., tables, 7 x 5 in., cloth. $1.50.

A concise, yet comprehensive presentation of the principles involved in the design and operation of friction clutches. Many recent devices are described and modern applications to many classes of machinery are shown.

LOCOMOTIVE CYCLOPEDIA OF AMERICAN PRACTICE. Seventh edition, 1925. Comp. & edited for the American Railway Association, Division V. Mechanical, by Roy V. Wright and Robert C. Augur. N. Y., Simmons-Boardman Pub. Co., 1925. 1130 pp., illus., diagrs., 12 x 9 in., cloth. $8.00.

The seventh edition retains the arrangement of matter adopted in 1922, by which all matter relating to each specific subject is grouped in a single chapter. The division into chapters, however, has been improved and the arrangement changed to a more convenient one.

The new edition includes the new designs of locomotives and appliances which have been developed in recent years. Like its predecessors, it gives the specifications of the American Railway Association, a wealth of drawings of locomotives, details and appliances, general illustrations, and descriptive matter issued by manufacturers.

MICHAEL FARADAY.

By Wilfrid L. Randell. Bost., Small, Maynard & Co., 1924. 192 pp., port., 7 x 5 in., cloth. $1.75.

A brief, readable life of Faraday, which attempts to present the man rather than the scientist. The author has made use of documents that were previously inaccessible, as well as of the standard biographies.

MODERN GAGING PRACTICE.

By Albert A. Dowd and Frank W. Curtis. N. Y., Engineering Magazine Co., 1925. (Industrial Management Library). 280 pp., illus., tables, 9 x 6 in., cloth. $3.00.

A descriptive work upon the limit system, gaging and inspection as used in interchangeable manufacture. The book is intended to acquaint laymen and novices with these matters and therefore omits highly technical descriptions.

MODERN PRACTICE IN MINING.

By R. A. S. Redmayne. 3rd edition. Lond. & N. Y., Longmans, Green & Co., 1925. 2 v., illus., diagrs., tables, 9 x 6 in., cloth. $3.75 each.

These books are the first of a new edition of this work which will be completed in five volumes. The work is intended as a comprehensive manual on coal mining, each volume being complete on a distinct department of the subject.

Volume one opens with a short description of the varieties of coal, their composition and occurrence. Brief directions for determining the value of fuels are given, followed by a chapter on geology applied to coal mining. The remainder of the volume two-thirds of the book, treats of methods of boring and is of value, not only to coal miners but to all mining engineers.

Volume two deals with shaft sinking and lining as carried out in British practice.

In the main, the text is a reprint of earlier editions. Obvious errors have been corrected, however, certain statistics have been brought up to date, and a new chapter on recent boring practice has been added to volume one.

MODERNE METALLKUNDE IN THEORIE UND PRAXIS.

By J. Czochralski. Berlin, Julius Springer, 1924. 292 pp., illus., diagrs., tables, 8 x 5 in., boards. 12.-gm.

Among the topics discussed are the chief varieties of binary-alloy solidification diagrams, the solidification diagrams of the commercial alloys, the principal varieties of phenomena produced by etching, methods of etching and the importance of molecular structure in foundry practice. Attention is also given to the crystallographic phenomena that accompany cold-working, recrystallization diagrams and reactions, the bedding theory and x-ray examinations, the principles of hardening processes, the phenomena of inner flow and their importance in working metals.

The book is not intended as a systematic textbook of metallography, but rather as a concise presentation of modern theories, to be used as a supplement to the classic treatises on metallurgy.

PATTERN MAKING.

By Joseph G. Horner. 5th edition, rev. & enl. Lond., Crosby Lockwood & Son, 1925. 437 pp., illus., tables, 9 x 6 in., cloth. 18 s.

The new edition of this well-known work has been thoroughly revised and rearranged and much new matter has been added. The book covers a large field, ranging from elementary constructions to the pattern work required for gear wheels and for machine molding.

PHYSIK. Edited by E. Lecher. 2nd edition. (Kultur der Gegenwart . . . . edited by Paul Hinneberg, t. 3, abt. 3, bd. 1). Lpz. u. Ber., B. G. Teubner, 1925. 849 pp., 10 x 7 in., boards. 36.-gm.

In this large volume, thirty-two specialists combine to give an account of the evolution and present state of our knowledge of the physical sciences. The book attempts the difficult task of surveying the field with sufficient detail to be useful to the physicist in search of a general review of the subject, and with a style and simplicity that will appeal to readers whose chief scientific interests lie in other fields. The result is an interesting, useful treatise, which tells the history of the various branches of physics and traces the development of the theories held.

PRINCIPLES OF PUBLIC HEALTH ENGINEERING.

By Earle B. Phelps. N. Y., Macmillan Co., 1925. 265 pp., illus., tables, 9 x 6 in., cloth. $3.00.

Contents: Introductory.—Atmospheric pollution.—Ventilation of buildings.—Municipal water supply.—Sewerage.—Pasteurization of milk.—Lighting.—Miscellaneous environmental control.—Index.

Represents the material used in a course on this subject recently established at Columbia University. The book is intended to furnish a public health background to the conventional course in sanitary engineering and an engineering viewpoint to the medically trained men doing public health work. The treatment is condensed and treats of principles rather than of practice.

STREET TRAFFIC CONTROL.

By Miller McClintock. N. Y., McGraw-Hill Book Co., 1925. 233 pp., illus., 9 x 6 in., cloth. $3.00.

The author analyzes the causes of traffic difficulties in city streets, with their accompanying accidents and congestion and summarizes the experiences of the larger American cities in coping with them. The conclusions of leading experts are presented.

Addresses Wanted

Beard, Harry F., 1232 So. 51st St., Philadelphia, Pa.
Darlington, Paul W., Cutler-Hammer Mfg. Co., Milwaukee, Wis.
De La Rochette, G., c/o Westinghouse Int'l. Co., 2 Norfolk St. Strand, London W. C. 2, England.
Gough, William J., Box 230, Sea Cliff, Long Island, N. Y.
Hansen, A. Fred, 462 West 37th Street, Los Angeles, Calif.
Hill, Edwin P., c/o Radio Corp. of America, Bolinas, Calif.
Hoey, William B., High Tension Supplies Co., Wilmington, Del.
Knott, Chas. E., San Luis, Obispo, Calif.
Law, E. D., Roderfield, West Va.
Mitchell, H. J., 42 Second Street, Elmhurst, Long Island, N. Y.
Watkins, I. B., 124 East Symmes Street, Norman, Ohio.

CHANGE OF MAILING ADDRESS OR BUSINESS RELATIONS

To facilitate the accuracy and proper entry of all addresses to be filed for Institute records, and for the greater convenience of our members and readers in furnishing same the following form is supplied.

My resident address for mail is

....

....

My present business connection is

(Title)..

(Company name and address)..

....

Signature ....

(To avoid misunderstanding please print or typewrite above information.)

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers as a cooperative bureau available only to their membership, and maintained by contributions from the societies and their individual members who are directly benefited.

MEN AVAILABLE.—Brief announcements will be published without charge and will not be repeated, except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case and with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ENGINEER, who has had at least five years' industrial experience. Work involves planning for requirements for a manufacturing plant. Must also have the ability to supervise the selection, arrangement and installation of plant equipment. Apply by letter with full particulars. Location, Chicago. R-6862.

ELECTRICAL ENGINEER, experienced in the manufacture and testing of magnetic material. Apply by letter, giving full particulars of experience and education, state age and salary expected. Location, Middlewest. R-6863.

ENGINEER, with power sales experience. Work will consist in dealing with and advising the company's customers. A thorough knowledge of rates and experience in electric sales engineering with public utilities are essential. Graduate engineer preferred. Apply by letter stating education, experience in detail, age and salary expected. Location, New York. R-6898.

MEN AVAILABLE

ELECTRICAL ENGINEER, Cornell graduate and Westinghouse Apprentice Course; thirteen years' experience in testing, inspection and other kinds of electrical work. Specialist on wire and cable, and now employed as such by consulting engineers on large hydroelectric development which is nearing completion. Location immaterial. B-3625.

GRADUATE ELECTRICAL ENGINEER, four and one-half years' experience in construction and maintenance of an electrical railway, also one year operating and power house installation experience. Desires a position with a company offering opportunities for advancement. Available on reasonable notice. Location immaterial. B-9660.

MECHANICAL AND ELECTRICAL ENGINEER, age 38, from Georgia. Maintenance, power house, steam turbine, boilers, combustion, research, efficiency, laboratory, fire prevention and safety. B-9035.

RECENT ELECTRICAL ENGINEERING GRADUATE 1925, age 24, single, Armenian, with three months' testing meters experience, desires operating position. Prefers to go into railway electrification work. Location immaterial. Available at once. Speaks English, Armenian, Turkish and can understand French and Arabic. Willing to accept foreign services in the future. C-51.

ELECTRICAL ENGINEER, university graduate, Westinghouse trained, finished Alexander Hamilton Institute course. Ten years' experience negotiations between small utilities and power transmission companies. Familiar with Federal Power Commission procedure and Safety Code applications. Will accept $3000 first year. C-49.

JUNIOR ENGINEER, electrical, age 24, B. S. in E. E. Has had eleven months' experience with large electric utility in Middlewest. Reason for change, desires employment in industrial, or utility work in the South. Available on reasonable notice. C-141.

YOUNG ELECTRICAL ENGINEER desires a permanent position with an engineering organization. Westinghouse Electric and Manufacturing Company and West Penn Company experience. B-9508.

ELECTRICAL ENGINEER, age 33, twelve years' experience in physical research, seven years' in radio work, including research on most recent phases of radio receiving apparatus. Thorough scientific and practical knowledge of radio equipment. Will consider responsible position with manufacturer of radio apparatus. B-165.

ELECTRICAL ENGINEER OR SUPERINTENDENT, graduate of leading engineering college, having long and practical experience with both hydro and steam generating stations, with transmission and distribution of electricity for public utilities and isolated plants, also applications of electric power to various industrial uses. B-3618.

ASSISTANT EXECUTIVE, technical graduate, age 33, married, desires connection with progressive company in commercial capacity, or industrial engineering firm. General experience covers manufacturing, time studies, plant layout, distribution systems, costs, sales, advertising and statistical studies of expenses, revenues and other administrative problems. Location, New England, New York. Available reasonable notice. B-9122.

ELECTRICAL ENGINEER, graduate 1917 B. S. in E. E., M. S., desires research, educational, editorial position. Two years' power plant operation and maintenance, Lieut. Signal Corps; one year editorial work, four years' electrical engineering teaching experience, elementary and advanced theory and laboratory. B-82.

GRADUATE, B. S. in E. E. from leading college, age 22, desires engineering experience in the electrical engineering field. Expects to combine study with work entered. Preferable location is Western Pennsylvania or proximity, others considered. C-98.

ELECTRICAL AND MECHANICAL ENGINEER, technically trained, experienced in operation, sales, plant executive work. Successful in economical generation of steam and electricity, and handling of men and materials. B-8448.

ELECTRICAL ENGINEER, executive, broad experience engineering and manufacturing field. Expert development and design of small apparatus and instruments, pyrometry. Manufacturing methods, standardization, quantity production, planning, factory organization and plant layouts. Desires connection with manufacturing concern, consulting or industrial engineer operating in manufacturing field. American, Christian. B-2721

ELECTRICAL ENGINEER, considerable experience, successful record development intricate electro-mechanical problems. Has been accustomed to make theoretical analysis, preliminary commercial survey, carrying out experiments, design, construction, patent routine. E. E., M. E. degrees. Fifteen years' practise here and abroad. Position desired New York City. U. S. Citizen, married, 39. Minimum salary $4000. A-165.

ELECTRICAL ENGINEER, age 30, technical school graduate, twelve years' experience on construction, installation, maintenance and inspection of light, power and signal systems. Has also worked in the capacity of assistant consulting engineer, sales engineer and branch manager, instructor and technical writer. Desires change with future for executive work. Location optional. B-247.

ELECTRICAL EDITOR, age 29, single, graduate E. E., B. P. I. 1923, five years' general electrical engineering experience, two years' intensive electrical editorial work. Good executive and administrator. Salary $2500. C-195.

ELECTRICAL ENGINEER, professional registered, technical graduate, age 35, executive ability with eighteen years' experience covering superintendent, estimator, inspector sales engineer, production engineer, designer, consulting engineer in contracting and consulting engineering field. Desires position with responsibility affording opportunity. B-6985.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before August 31, 1925.

Ackerman, G. E., Line Material Co., South Milwaukee, Wis.
Agostinacchio, V., Yankee Radio Co. of America, Newark, N. J.
Allende, O. E., General Electric Co., Schenectady, N. Y.
Alvung, R., Standard Steel Car Co., Butler, Pa.
Arnold, R. M., The Arnold Engineering Co., Chicago, Ill.
Bazarian, M. H., (Member), Chase Metal Works, Waterville, Conn.
Bennington, R. F., Hub Engineering Corp., New York, N. Y.
Bradford, A. J., General Electric Co., Schenectady, N. Y.
Buller, F. H., General Electric Co., Schenectady, N. Y.
Carder, R. C., Sanderson & Porter, Inc., New York, N. Y.
Cary, C. R., (Member), Leeds & Northrup Co., Philadelphia, Pa.
Daniel, L. H., Industrial Engineering Corp., Havana, Cuba
Dave, S. B., Ford Motor Co., River Rouge, Mich.
De Santis, J., 1659 W. 11th St., Brooklyn, N. Y.
Edson, W. W., (Member), Edison Elec. Ill. Co. of Boston, Boston, Mass.
Fitch, C. S., So. California Edison Co., Big Creek, Calif.
Foster, N. C., The Ohio Public Service Co., Cleveland, Ohio
Frost, G., Bristol Electric Light Co., Bristol, N. H.
Goldsmith, L. M., (Member), Atlantic Refining Co., Philadelphia, Pa.
Hansen, E. H., International News Service, New York, N. Y.
Harrison, J. K. M., (Member), Harrison & Co., Philadelphia, Pa.
Harvey, J. L., Adirondack Power & Light Corp., Schenectady, N. Y.
Henn, W. F., General Electric Co., Philadelphia, Pa.
Holtzberg, A. G., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Hon, T H., General Electric Co., West Lynn, Mass.
Humphreys, J. F., Public Service Electric & Gas Co., Hackensack, N. J.
Hyatt, C. B., Radio Engineer, 1701 Arch St., Philadelphia, Pa.
Isele, H. A., Pratt Institute, Brooklyn, N. Y.
Jacobson, M., Colonial Radio Corp., Long Island City, N. Y.
Kellerstedt, H. P., Pratt Institute, Brooklyn, N.Y.
Ketchum, W. D., General Electric Co., Lynn, Mass.
Krebs, W. W., Roanoke Railway & Electric Co., Roanoke, Va.
Leeman, W. J., U. S. S. Concord, c/o Postmaster, New York, N. Y.
Lewis, D. L., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
McCann, C. S., with Hugh L. Cooper & Co., Wilson Dam, Florence, Ala.
McFadden, H. C., 56 Irving Place, Passaic, N. J.
Miller, H. L., Woodfield-Thompson Co., Philadelphia, Pa.
Miller, O. G., Standard Underground Cable Co., New York, N. Y.
Minasian, G. T., New York Edison Co., New York, N. Y.
Miroddi, S., Brooklyn Edison Co., Brooklyn, N.Y.
Newell, P. E., Western Electric Co., Inc., Jersey City, N. J.
Peterson, R. W., Murrie & Co., Inc., New York, N. Y.
Postal, H., 1773 Amsterdam Ave., New York, N. Y.
Prigmore, D. C., Bureau of Power & Light, Los Angeles, Calif.
Pumphrey, F. H., (Member), Staten Island Edison Corp., Livingston, S. I., N. Y.
Sanborn, C. A., (Member), Cons. Elec. & Mech. Engineer, Los Angeles, Calif.
Siconolfi, M., Draftsman, 1998 Madison Ave., New York, N. Y.
Stein, A. P., Public Service Co. of No. Illinois, Evanston, Ill.
Wagner, H. A., (Member), Consulting Engineer, Mayer, Ariz.
Watson, W., Sir W. G. Armstrong Whitworth & Co., Ltd., Deer Lake, Newfoundland
Wonham, W. R., Montreal Tramways Co., Montreal, Que., Can.
Woodbury, E., U. S. Patent Office, Washington, D. C.
Woods, S. R., Westinghouse Elec. & Mfg. Co., Murfreesboro, Tenn.
Young, C. E., Western Union Tel. Co., Kansas City, Mo.
Total 54

Foreign

Goodlet, B. L., Metropolitan-Vickers Elec. Co., Ltd., Manchester, Eng.
Hughes E., Municipal Technical College, Brighton, Eng.
Total 2

OFFICERS OF A. I. E. E. 1924-1925

President
M. I. Pupin

Junior Past Presidents
Farley Osgood
Harris J. Ryan

Vice-Presidents
Harold B. Smith
Edward Bennett
John Harisberger
L. F. Morehouse
H. W. Eales
P. M. Downing
Herbert S. Sands
W. E. Mitchell
Arthur G. Pierce
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G. L. Knight
William M. McConahey
W. K. Vanderpoel
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E. B. Merriam
M. M. Fowler
H. A. Kidder
E. C. Stone

National Treasurer
George A. Hamilton

National Secretary
F. L. Hutchinson

Honorary Secretary
Ralph W. Pope

LOCAL HONORARY SECRETARIES

T. J. Fleming, Calle B. Mitre 519, Buenos Aires, Argentina, S. A.
Carroll M. Mauseau, Caixa Postal No. 571, Rio de Janiero, Brazil, S. A.
Charles le Maistre, 28 Victoria St., London, S. W. 1, England.
A. S. Garfield, 45 Bd. Beausejour, Paris 16 E, France.
H. P. Gibbs, Tata Sons Ltd., 24 Bruce Road, Bombay—1, India.
Guido Semenza, 39 Via Monte Napoleone, Milan, Italy.
Eiji Aoyagi, Kyoto Imperial University, Kyoto, Japan.
Axel F. Enstrom, 24a Grefturegatan, Stockholm, Sweden.
W. Elsdon-Dew, P. O. Box 4563, Johannesburg, Transvaal, Africa.

A. I. E. E. COMMITTEES

The list of committees is omitted from this issue, as new appointments are being made for the administrative year commencing August 1. The new committees will be listed in the September issue.

A. I. E. E. REPRESENTATION

A complete list of A. I. E. E. representatives on various bodies will be published in the September issue.

LIST OF SECTIONS

Name	Chairman	Secretary
Akron	Ralph Higgins	G. L. Sanderson, 887 Work Drive, Akron, Ohio
Atlanta	W. E. Gathright	W. F. Oliver, Box 2211, Atlanta, Ga.
Baltimore	W. B. Kouwenhoven	R. T. Greer, Lexington Building, Baltimore, Md.
Boston	W. R. McCann	W. H. Colburn, 39 Boylston Street, Boston, Mass.
Chicago	George H. Jones	K. A. Auty, Room 1000, Edison Building, Chicago, Ill.
Cincinnati	H. C. Blackwell	E. S. Fields, Union Gas & Electric Co., Cincinnati, Ohio
Cleveland	Chester L. Dows	J. F. Schnable, Elec. Controller & Mfg. Co., Cleveland, Ohio
Columbus	F. R. Price	O. A. Robins, 1517 Franklin Ave., Columbus, Ohio
Connecticut	A. A. Packard	A. E. Knowlton, Dunham Laboratory, Yale University, New Haven, Conn.
Denver	V. L. Board	R. B. Bonney, Telephone Building, P. O. Box 960, Denver, Colo.
Detroit-Ann Arbor	G. B. McCabe	Harold Cole, Detroit Edison Co., 2000 Second Ave., Detroit, Mich.
Erie	H. J. Hansen	L. H. Curtis, General Electric Co., Erie, Pa.
Fort Wayne	E. L. Gaines	D. W. Merchant, General Electric Co., Fort Wayne, Ind.
Indianapolis-Lafayette	V. T. Mavity	J. B. Bailey, 48 Monument Circle, Indianapolis, Ind.
Ithaca	J. G. Pertsch, Jr.	Geo. F. Bason, Cornell University, Ithaca, N. Y.
Kansas City	F. S. Dewey	Henry Nixon, 509 Mutual Building, Kansas City, Mo.
Lehigh Valley	W. H. Lesser	G. W. Brooks, Pennsylvania Power & Light Co., Allentown, Pa.
Los Angeles	C. A. Heinze	R. A. Hopkins, 420 S. San Pedro St., Los Angeles, Calif.
Lynn	E. D. Dickinson	F. S. Jones, General ElectricCo., Lynn, Mass.
Madison	L. E. A. Kelso	Leo J. Peters, University of Wisconsin, Madison, Wis.
Mexico	D. K. Lewis	E. F. Lopez, Fresno No. 111, Mexico, D. F., Mexico
Milwaukee	H. R. Huntley	L. F. Seybold, 446 Public Service Building, Milwaukee, Wis.
Minnesota	A. G. Dewars	J. E. Sumpter, 940 Security Building, Minneapolis, Minn.
Nebraska	P. M. McCullough	C. W. Minard, 509 Electric Building, Omaha, Neb.
New York	H. A. Kidder	H. V. Bozell, Bonbright & Co., 25 Nassau St., New York, N. Y.
Niagara Frontier	J. Allen Johnson	A. W. Underhill, Jr., 605 Lafayette Building, Buffalo, N. Y.
Oklahoma	E. R. Page	A. D. Stoddard, Box 382, Bartlesville, Okla.
Panama	L. W. Parsons	I. F. McIlhenny, Box 413, Balboa Heights, C. Z.
Philadelphia	C. D. Fawcett	R. H. Silbert, 2301 Market St., Philadelphia, Pa.
Pittsburgh	G. S. Humphrey	W. C. Goodwin, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Pittsfield	E. D. Eby	C. H. Kline, General Electric Co., Pittsfield, Mass.
Portland, Ore.	L. W. Ross	J. C. Henkle, Hawthorne Building, Portland, Ore.
Providence	W. P. Field	F. N. Tompkins, Brown University, Providence, R. I.
Rochester	A. E. Soderholm	Earl C. Karker, Mechanics Institute, Rochester, N. Y.
St. Louis	Fred D. Lyon	Ralf T. Toensfeldt, 311 City Hall, St. Louis, Mo.
San Francisco	F. R. George	A. G. Jones, 807 Rialto Building, San Francisco, Calif.
Schenectady	W. J. Davis, Jr.	W. E. Saupe, Bldg. No. 41, General Electric Co., Schenectady, N. Y.
Seattle	E- A. Loew	C. E. Mong, 505 Telephone Building, Seattle, Wash.
Southern Virginia	H. B. Hawkins	E. W. Trafford, 1030 W. Franklin St., Richmond, Va.
Spokane	G. S. Covey	Richard McKay, Washington Water Power Co., Lincoln & Trent, Spokane, Wash.
Springfield, Mass.	G. W. Atkinson	J. Frank Murray, 251 Wilbraham Ave., Springfield, Mass.
Syracuse	W. C. Pearce	L. N. Street, College of Applied Science, Syracuse University, Syracuse, N. Y.
Toledo	A. H. Stebbins	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio
Toronto	L. B. Chubbuck	W. L. Amos, Hydro-Elec. Power Commission, 190 University Ave., Toronto, Ont.
Urbana	C. A. Keener	J. T. Tykociner, 300 Electrical Laboratory, University of Illinois, Urbana, Ill.
Utah	John Salberg	D. L. Brundige, Utah Pr. & Lt. Co., Box 1790, Salt Lake City, Utah.
Vancouver	A. Vilstrup	C. W. Colvin, B. C. Elec. Railway Co., Hastings St., Vancouver, B. C.
Washington, D. C.	A. F. E. Horn	L. E. Reed, 482 G St., S. W., Washington, D. C.
Worcester	E. T. Harrop	Fred B. Crosby, 15 Belmont St., Worcester, Mass.
Total 49		

LIST OF BRANCHES

Name and Location	Chairman	Secretary
Alabama Poly Inst., Auburn, Ala.	C. W. McMullan	W. E. Hooper
Alabama, Univ. of, University, Ala.	C. E. Rankin	Sewell St. John
Arizona, Univ. of, Tucson, Ariz.	C. A. Rollins	B. L. Jones
Arkansas, Univ. of, Fayetteville, Ark.	Hugh McCain	R. T. Purdy
Armour Inst. of Tech., Chicago, Ill.	A. L. Steamwedel	W. H. Sothen
Brooklyn Poly Inst., Brooklyn, N. Y.	J. C. Arnell	J. H. Diercks
Bucknell Univ., Lewisburg, Pa.	W. A. Stevens	R. J. Clingerman
California Inst. of Tech., Pasadena	W. A. Lewis	A. E. Schueler
California, Univ. of, Berkeley, Calif.	R. A. Hurley	J. M. Edwards
Carnegie Inst. of Tech., Pittsburgh, Pa.	G. L. LeBaron	H. E. Ashworth
Case School of Applied Science, Cleveland, O.	F. B. Schramm	G. J. Goudreau
Catholic Univ. of America, Washington, D. C.	K. T. Williamson	G. B. Mangam
Cincinnati, Univ. of, Cincinnati, O.	R. T. Congleton	W. C. Osterbrook
Clarkson Coll. of Tech., Potsdam, N.Y.	F. H. Porter	F. S. McGowan
Clemson Agri. College, Clemson College, S. C.	R. W. Pugh	O. A. Roberts
Colorado State Agri. Coll., Ft. Collins	S. Aldrich	F. E. Bodine
Colorado, Univ. of, Boulder, Colo.	O. V. Miller	L. E. Swedlund
Cooper Union, New York	E. J. Kennedy	A. W. Carlson
Denver, Univ. of, Denver, Colo.	Earl Reed	R. L. Kuhler
Drexel Institute, Philadelphia, Pa.	J. P. Carr	W. P. Turner
Florida, Univ. of, Gainesville, Fla.	J. Weil	C. Washburn, Jr.
Georgia School of Tech., Atlanta, Ga.	S. M. Thomas	C. E. Burke
Idaho, University of, Moscow, Idaho	R. C. Beam	James Gartin
Iowa State College, Ames, Iowa	V. Womeldorf	G. G. Thomas
Iowa, Univ. of, Iowa City, Iowa	G. C. K. Johnson	C. A. Von Hoene
Kansas State College, Manhattan	R. B. McIlvain	G. J. McKimens
Kansas, Univ. of, Lawrence, Kans.	C. H. Freese	G. R. Vernon
Kentucky, Univ. of, Lexington, Ky.	R. K. Giovannoli	J. M. Willis
Lafayette College, Easton, Pa.	J. B. Powell	P. O. Farnham
Lehigh Univ., S. Bethlehem, Pa.	E. W. Baker	D. C. Luce
Lewis Institute, Chicago, Ill.	E. Millison	C. P. Meek
Maine, Univ. of, Orono, Me.	R. N. Haskell	S. B. Coleman
Marquette Univ., Milwaukee, Wis.	C. H. Legler	M. J. Smith
Massachusetts Inst. of Tech., Cambridge, Mass.	Stuart John	H. W. Geyer
Michigan State Coll., East Lansing	D. D. Miller	L. A. Traub
Michigan, Univ. of, Ann Arbor, Mich.	M. H. Nelson	S. L. Burgwin
Milwaukee Engg. School of, Milwaukee, Wis.	L. C. Eddy	E. L. Ruth
Minnesota, Univ. of, Minneapolis	R. W. Kellar	H. R. Reed
Missouri, Univ. of, Columbia, Mo.	M. P. Weinbach	L. Spraragen
Missouri School of Mines and Metallurgy, Rolla, Mo.	T. C. Adcock	J. D. Behnke
Montana State Coll., Bozeman, Mont.	W. A. Boyer	J. A. Thaler
Nebraska, Univ. of, Lincoln, Neb.	M. E. LaBounty	C. J. Madsen
Nevada, Univ. of, Reno, Nev.	Lloyd Crosby	R. C. Samuels
New York, College of the City of, New York, N. Y.	S. E. Gottschall	Frank Kulman
New York Univ., New York, N. Y.	D. Wright	J. P. Della Corte
North Carolina State College, Raleigh, N. C.	F. P. Dickens	H. Baum
North Carolina, Univ. of, Chapel Hill	H. Klingenschmitt	J. D. McConnell
North Dakota, Univ. of, University	Leo Frank	D. Donaldson
Northeastern Univ., Boston, Mass.	E. H. Barker	C. M. McCoombe
Notre Dame, Univ. of, Notre Dame, Ind.	M. A. Brule	J. A. Kelley, Jr.
Ohio Northern Univ., Ada, Ohio	H. N. Seslar	Frank Boulton
Ohio State Univ., Columbus, O.	L. W. Hendershott	F. S. Kinkead
Oklahoma A. & M. Coll., Stillwater	B. Wrigley	K. Woodyard
Oklahoma, Univ. of, Norman, Okla.	R. E. Thornton	F. O. Bond
Oregon Agri. Coll., Corvallis, Ore.	H. E. Rhoades	B. E. Plowman
Pennsylvania State Collge, State College, Pa.	W. L. Kochler	J. E. Hogan
Pennsylvania, Univ. of, Philadelphia	H. W. Steinhoff	J. W. Emling
Pittsburgh, Univ. of, Pittsburgh, Pa.	E. A. Casey	J. E. Lange
Purdue Univ., Lafayette, Ind.	W. O. Osbon	R. C. Parker
Rensselaer Poly. Inst., Troy, N. Y.	F. M. Sebast	K. C. Wilsey
Rhode IslandState Coll., Kingston, R.I.	D. B. Brown	S. J. Bragg
Rose Poly. Inst., Terre Haute, Ind.	P. Wilkens	R. A. Reddie
Rutgers University, New Brunswick, N. J.	StanleyHunt	S. B. Aylsworth
South Dakota State School of Mines, Rapid City, S. D.	J. V. Walrod	C. Allen
SouthDakota, Univ.of, Vermillion, S. D.	C. Barret	H. Babb
Southern California, Univ. of, Los Angeles, Calif.	C. B. Little	J. Shideler
Stanford Univ., Stanford Univeristy, Calif.	F. E. Crever	C. R. Walling
Swarthmore Coll., Swarthmore, Pa.	C. J. Wenzinger	J. S. Donal, Jr.
Syracuse Univ., Syracuse, N. Y.	W. D. Johnson	W. E. Phillips
Tennessee, Univ. of, Knoxville, Tenn.	S. R. Woods	F. J. Guice
Texas A. & M. Coll., College Station	A. A. Ward	L. H. Cardwell
Texas, Univ. of, Austin, Tex.	A. A. Bown	J. B. Coltharp
Utah, Univ. of, Salt Lake City, Utah	S. W. Pixton	H. H. Tracy
Virginia Military Inst., Lexington	H. F. Watson	J. P. Black
Virginia Poly. Inst., Blacksburg, Va.	E. M. Melton	M. R. Staley
Virginia, Univ. of, University, Va.	T. M. Linville	H. M. Dixon
Washington, State Coll. of, Pullman	Tom Hunt	C. H. Backus
Washington Univ., St. Louis, Mo.	W. W. Braken	S. E. Newhouse, Jr.
Washington, Univ. of, Seattle, Wash.	J. Nordahl	J. W. Lewis
West Virginia Univ., Morgantown	W. W. Mountain	J. U. Neill
Wisconsin, Univ. of, Madison, Wis.	N. G. Robisch	Stanley Roland
Yale Univ., New Haven, Conn.	E. H. Eames	F. F. Tomaino
Total 82		

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Switchboards.—Catalog 8700-E, 120 pp. Covers the installation, operation and maintenance of switchboards. General Electric Company, Schenectady, N. Y.

Ball Bearings.—Bulletin on lubrication of ball bearings applied to electric motors. Standard Steel & Bearings, Inc., Plainville, Conn.

Potentiometer Pyrometers.—Catalog 87, 56 pp. Describes various types of potentiometer pyrometers. Leeds & Northrup Company, 4901 Stenton Avenue, Philadelphia, Pa.

Transformers.—Bulletin 2046, 4 pp. Describes Pittsburgh film-type radiator for self-cooled transformers. Pittsburgh Transformer Company, Columbus & Preble Aves., Pittsburgh, Pa.

Electrical Specialties.—Catalog 412, 60 pp. Covers a complete line of conduit, armored cable, metal moulding, switch and cutout cabinets, junction and outlet boxes. Bonnell Electric Manufacturing Co., 192 Chambers St., New York.

Battery Charging Motor Generators.—Bulletin 52, 62 pp., describes a-c. to d-c. and d-c. to d-c. motor generators, vertical and horizontal types, for charging storage batteries in electric industrial trucks, tractors and locomotives. The Electric Products Co., Clarkstone Road, Cleveland, Ohio.

Stokers.—Bulletin 1018, 32 pp. Describes Detroit underfeed stokers of the single retort type. The bulletin contains a number of bed cross sections showing conditions of the fire with respect to air distribution and movement toward the dumps. One section of the book is devoted to the application of the stoker to both low and high set boilers. Another section shows how twin settings serve very large boilers. Detroit Stoker Company, General Motors Bldg., Detroit, Michigan.

NOTES OF THE INDUSTRY

General Electric Company Orders.—Gerard Swope, president of the General Electric Company, announced that orders received by the company for the three months ending June 30 amount to $66,468,992, compared with $71,219,984 for the same period in 1924, a decrease of seven per cent. For the six months of the present year, orders total $150,315,228, compared with $144,707,887 for the first half of 1924, an increase of four per cent.

Large Contract for Combustion Engineering Corporation.—The Combustion Engineering Corporation, New York, has been awarded the complete contract, amounting to approximately one million dollars, for the pulverized coal preparation plant, including all burning equipment, such as water cooled furnaces, air heaters and air transport systems which will convey the coal to the furnaces, to be installed in the new 14th Street power plant of the New York Edison Company.

New Westinghouse Office Building.—An 11-story office building 136 ft. high and 56 ft. wide costing approximately a million dollars will be built at the East Pittsburgh Works of the Westinghouse Electric and Manufacturing Company to take care of continued expansion of business. Small buildings on the site of the new structure have been razed, and erection of the building will be completed within a year. The new building will centralize the office forces of the various departments which are now scattered throughout the factory. It will add 175,000 square ft. to the present office floor area at the plant.

Allis-Chalmers to Build 50,000 Kw. Turbine.—The Allis-Chalmers Manufacturing Company, Milwaukee, has received an order for a 50,000 K. W. steam turbine unit to be installed in the Waukegan Station of the Public Service Company of Northern Illinois. This is the third unit for this station, the first being a 25,000 K. W. Allis-Chalmers unit, which has been in operation for a number of years. The second unit, a 35,000 K. W. Allis-Chalmers unit was placed in operation last winter. The new unit as well as the two units previously installed operate in connection with Allis-Chalmers condensers.

New Westinghouse Instrument Section.—The steady increasing growth of the meter section, which up until now handled both the electric instruments as well as meters, has made it necessary for the Westinghouse Electric and Manufacturing Company to create a separate section for instruments. Mr. R. T. Pierce, formerly of the Supply Engineering Section, will be manager of this new section, with offices located in Newark, N. J., where both instruments and meters are manufactured.

The new section will handle indicating, portable and recording instruments, relays, and instrument transformers. The instrument transformers are being manufactured in the Sharon works of the company. Mr. Pierce will have an assistant located at Sharon.

S. A. Berger, Newark manager of the Meter Section, will remain as manager of the section, which will handle the company's electric meters.

135,000 H. P. at Cherokee Bluffs.—The installation of waterwheel-driven generators in the new Cherokee Bluffs plant of the Alabama Power Company will total 135,000 horse power. There will be three 45,000 horse power (37,500 kv-a.) units, the largest in the southern states. With the exception of those at Niagara Falls, they will be the largest in the United States. All of the generators are being furnished by the General Electric Company. Two of the waterwheels will be supplied by the Allis-Chalmers Manufacturing Company, and the third by the William Cramp and Sons Ship and Engine Building Company. The generators are rated 37,500 kv-a., 88 per cent power factor, 120 r. p. m., 12,000 v., three phase, 60 cycle, vertical shaft, with direct-connected exciter, and General Electric spring thrust bearings. It is expected that the plant, which will be interconnected with the other plants of the company, will be completed during 1926. The water storage plant will provide the greatest artificial lake in the world, with an impounding capacity of 530 billion gallons of water. It will have a shore line of 700 miles and will cover 40,000 acres. Roosevelt Dam Reservoir, at present the largest artificial body of water, holds 420 billion gallons.

Engineering Professors Visit Schenectady.—Twenty-one professors, representing various colleges throughout the United States, visited the Schenectady plant of the General Electric Company during June and July for the purpose of obtaining first hand knowledge of engineering and factory methods as carried out in a large manufacturing plant. The following professors took part in the visit lasting from June 22 to July 25 this year:

E. A. Bureau, Univ. of Kentucky, H. V. Carpenter, Washington State College, A. H. Casberg, Univ. of Illinois, O. E. Edison, Univ. of Nebraska, J. E. Emswiler, Univ. of Michigan, R. B. George, Oklahoma A .& M., R. W. Goddard, New Mexico A. & M. A., O. K. Harlan, Penn. State College, C. W. Henderson, Syracuse University, D. R. Jenkins, Univ. of No. Dakota, D. Kavanough, Clemson College, C. F. Lee, Virginia Poly. Institute, A. H. Lovell, Univ. of Michigan, W. H. Martin, Oregon A. & M., C. M. McCormick, Univ. of Colorado, P. O. Owens, Case School of Applied Science, C. A. Perkins, Univ. of Tenn., W. B. Stelzner, Univ. of Arkansas, S. C. Stovall, Georgia School of Tech., R. C. Warner, Yale University, E. O. Water, Yale University.